GODDARD SPACE FLIGHT CENTER

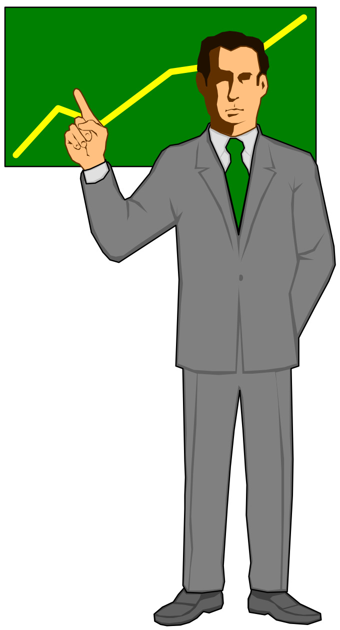
March 12, 2001

EARTH OBSERVING-1

Engineering Colloquium

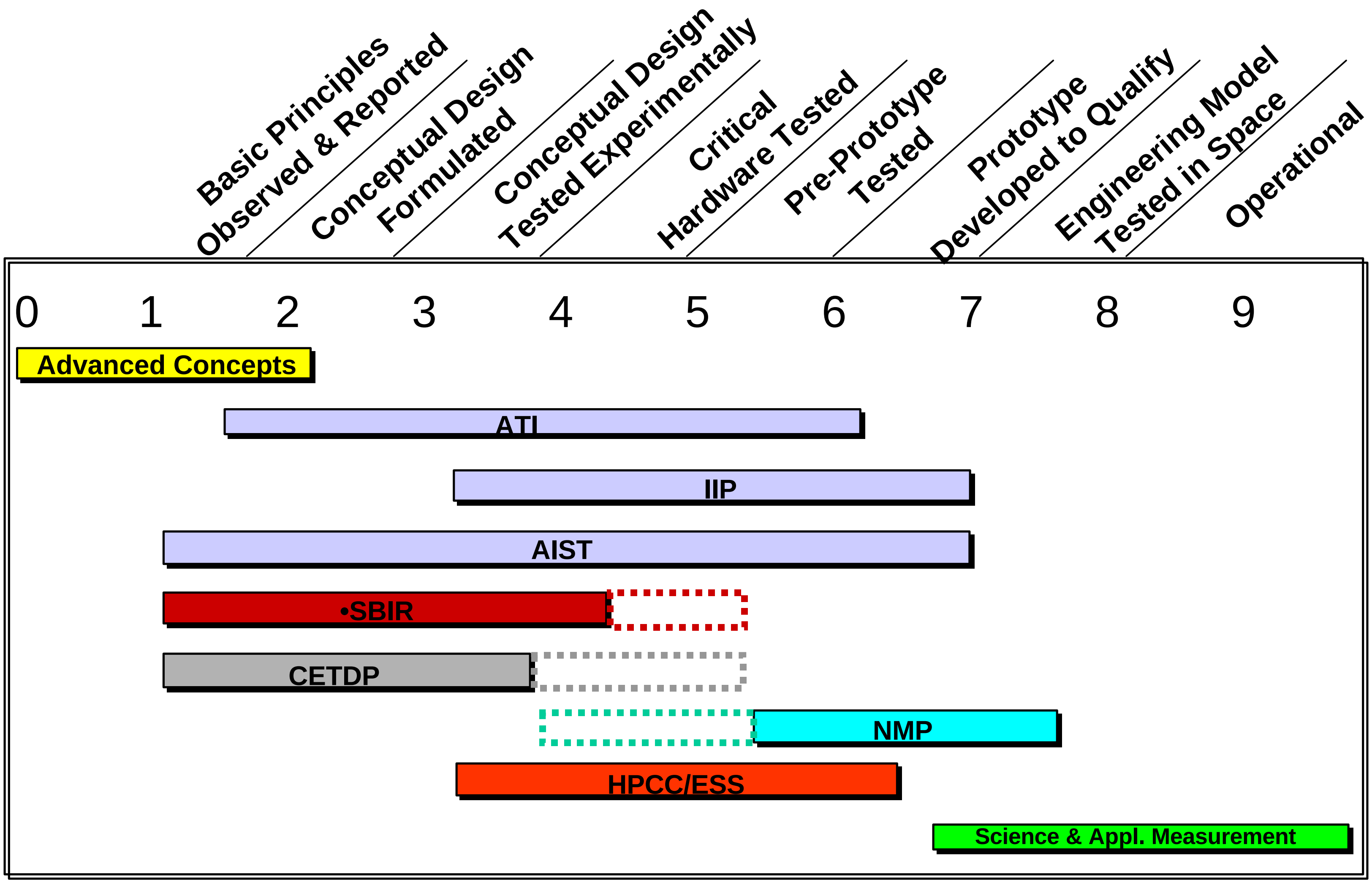
. . . Dale Schulz
Earth Observing-1 Project Manager

New Millennium Goals



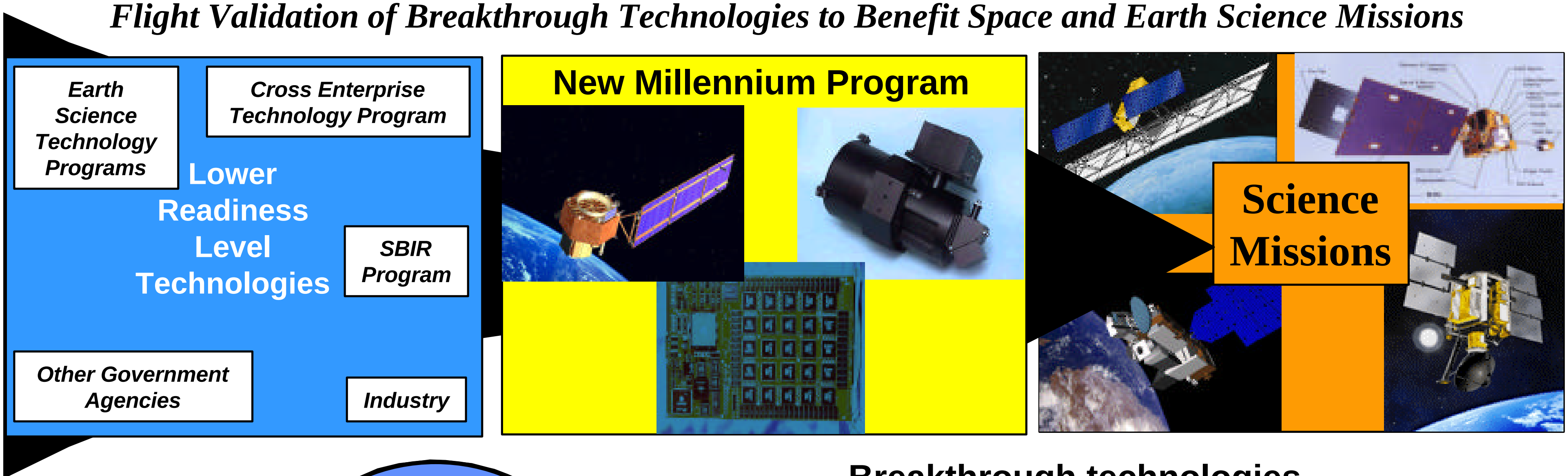
- ***The New Millennium Program (NMP) was established in 1994 to revolutionize NASA's Space and Earth science programs to help them cope with simultaneous decreasing budgets and enhanced capability requirements by:***
  - *Developing and flight-validating revolutionary technologies for more capable missions*
  - *Reducing development times and life cycle mission costs*
  - *Enabling highly capable and autonomous spacecraft*
  - *Promoting nationwide teaming and coordination with industry and academia*

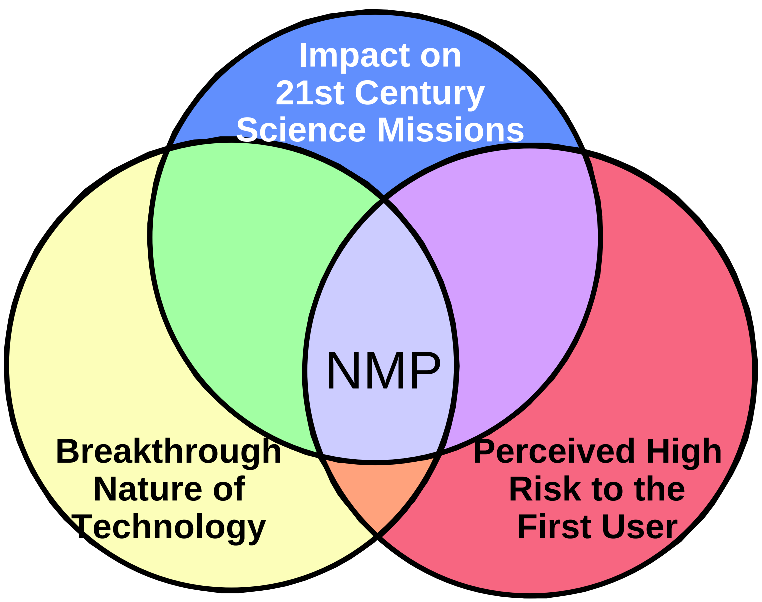
Technology Readiness Levels



NMP ROLE

Flight Validation of Breakthrough Technologies to Benefit Space and Earth Science Missions





Breakthrough technologies

- Enable new capabilities to meet Science needs
- Reduce costs of future missions

Flight validation

- Mitigates risks to first users
- Enables rapid technology infusion into future missions

NMP Technology Categories

CATEGORY I

- *Essential Technology*
- *Willing to restructure mission in order to fly it*
- *If technology gets into trouble -- you fix it*
- *Part of minimum mission*

CATEGORY II

- *Technology provides an essential mission function*
- *A conventional approach is pre-planned*
- *If technology gets into trouble -- you switch to the conventional approach*

CATEGORY III

- *Technology exercises a flight opportunity*
- *If technology gets into trouble -- you defer it to a later flight*

Technology Transfer and Infusion

- ***Validation Plans are developed and executed for each assigned technology***
- ***Each validation plan has two parts:***
  - *Technical (engineering tests)*
  - *Science (data evaluation)*
- ***The Mission Technologist and Technology Provider prepare Technology Transfer documentation:***
  - *Design features*
  - *Ground-based test results*
  - *On-orbit validation*
  - *Operational experience*
  - *Likely applications*
  - *Technology Infusion opportunities*
- ***NMP workshops, technology fairs, etc. are used to disseminate the Technology Transfer documentation***
- ***NMP works closely with Earth and Space Science Program Offices to infuse technology into future science missions***

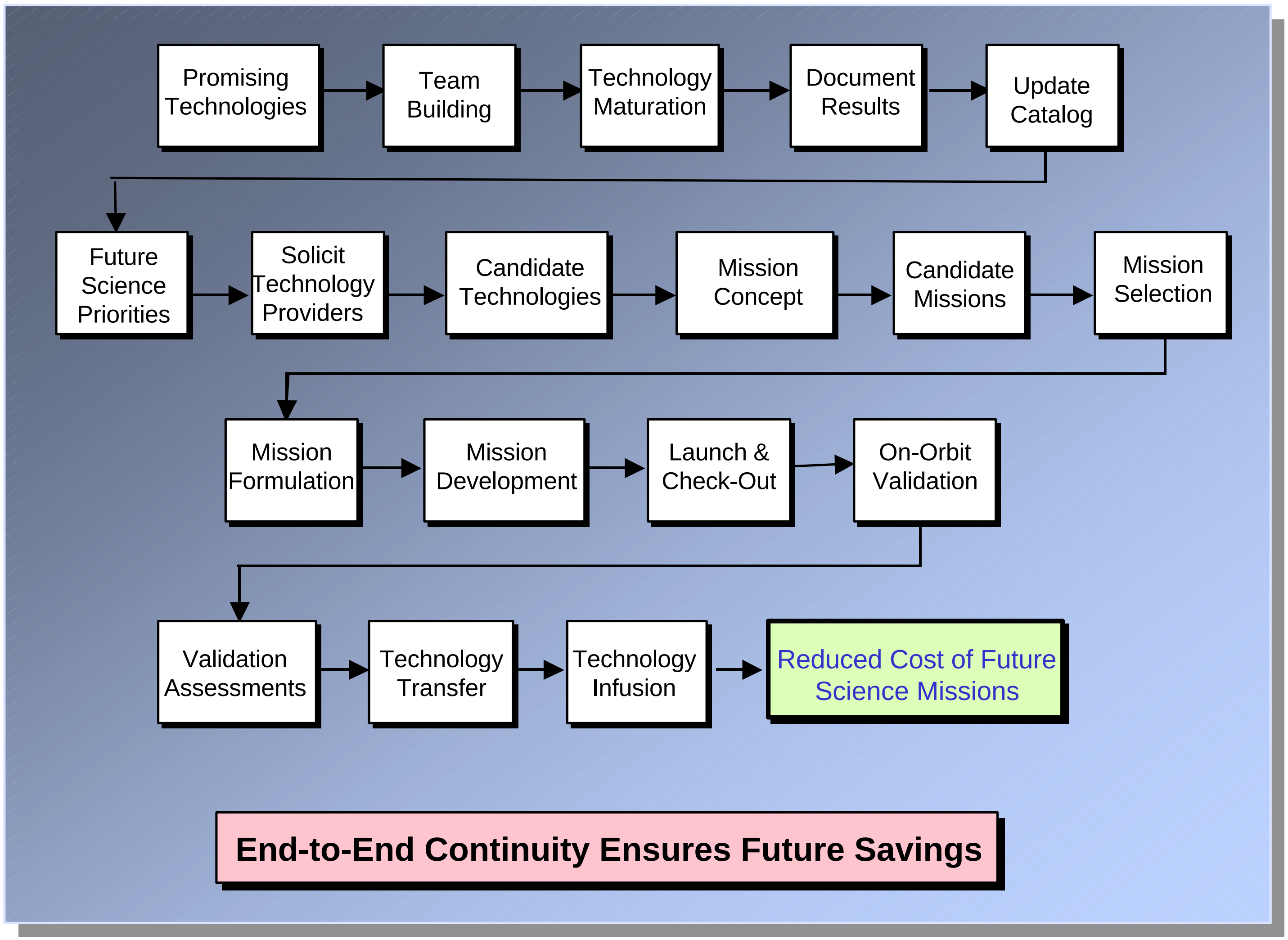
NMP Technology Evolution

SEEDING

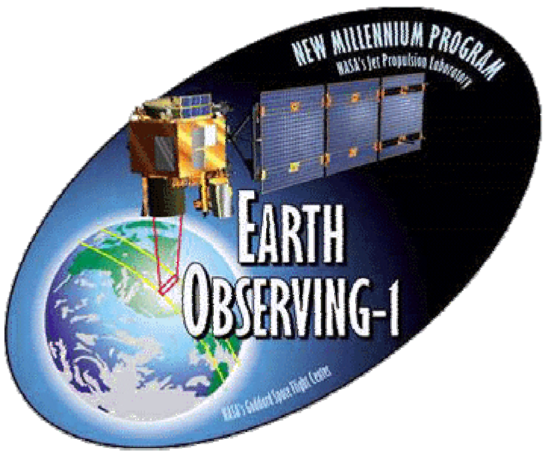
SELECTING

DEVELOPING

VALIDATING



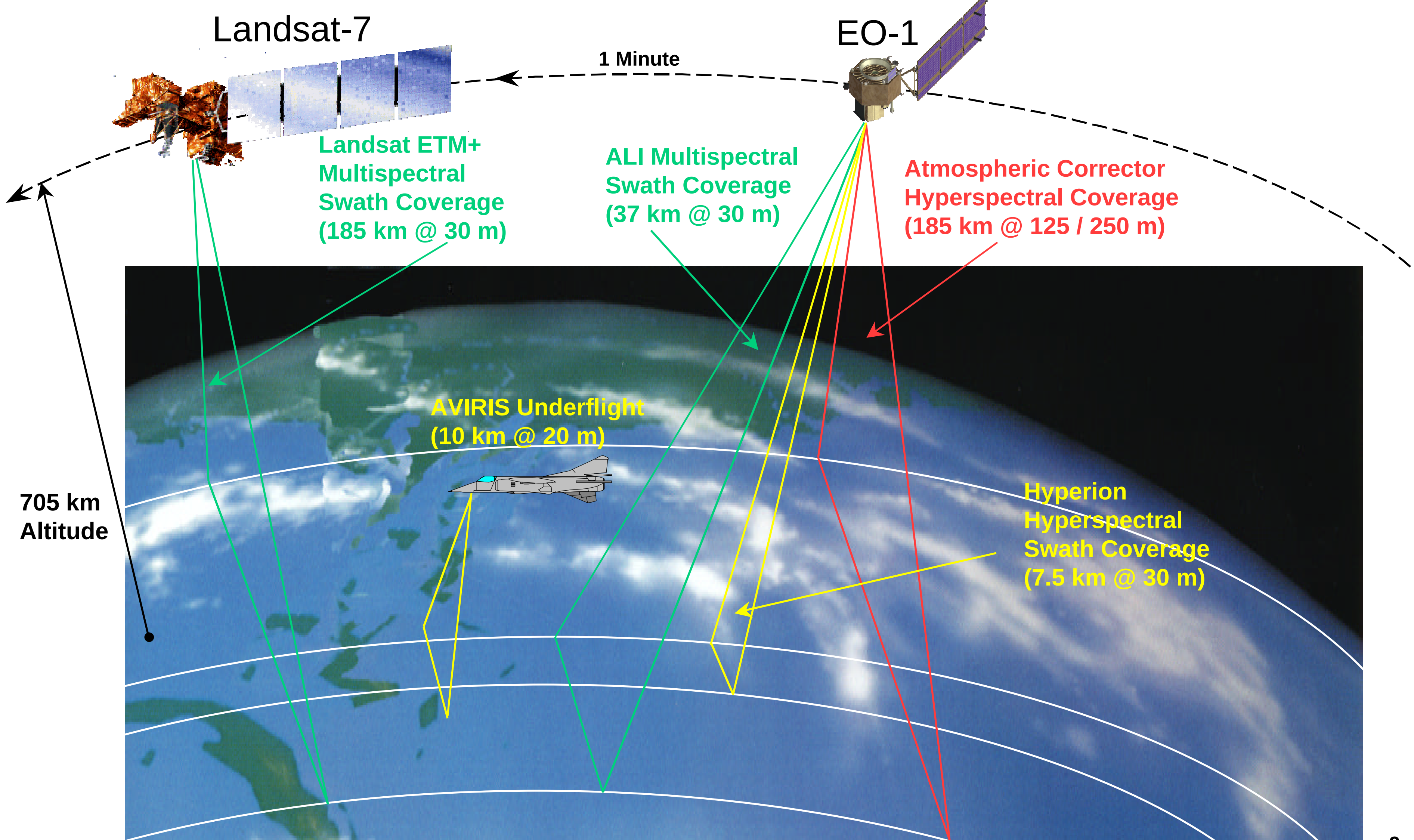
What is EO-1?



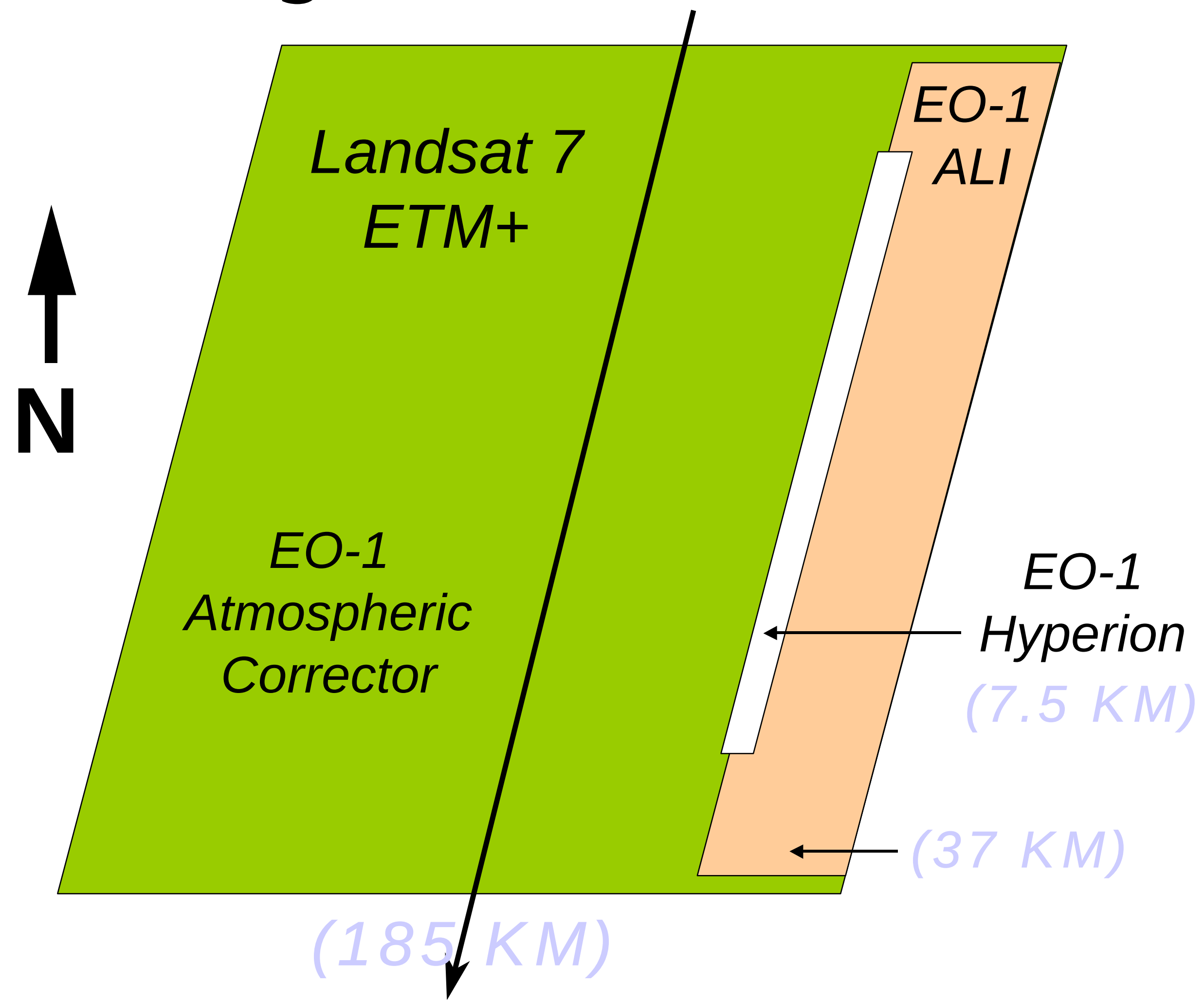
Visit the
Web Site @
http://eo1.gsfc.nasa.gov/

- ***Designed to flight validate breakthrough technologies applicable to Landsat follow-on missions***
- ***Specifically responsive to the Land Remote Sensing Policy Act of 1992 (Public Law 102-55) wherein NASA is charged to ensure Landsat data continuity through the use of advanced technology:***
  - *Multispectral Imaging Capability to address traditional Landsat user community*
  - *Hyperspectral Imaging Capability to address Landsat research-oriented community -- backward compatibility essential*
  - *Atmospheric correction to compensate for intervening atmosphere*

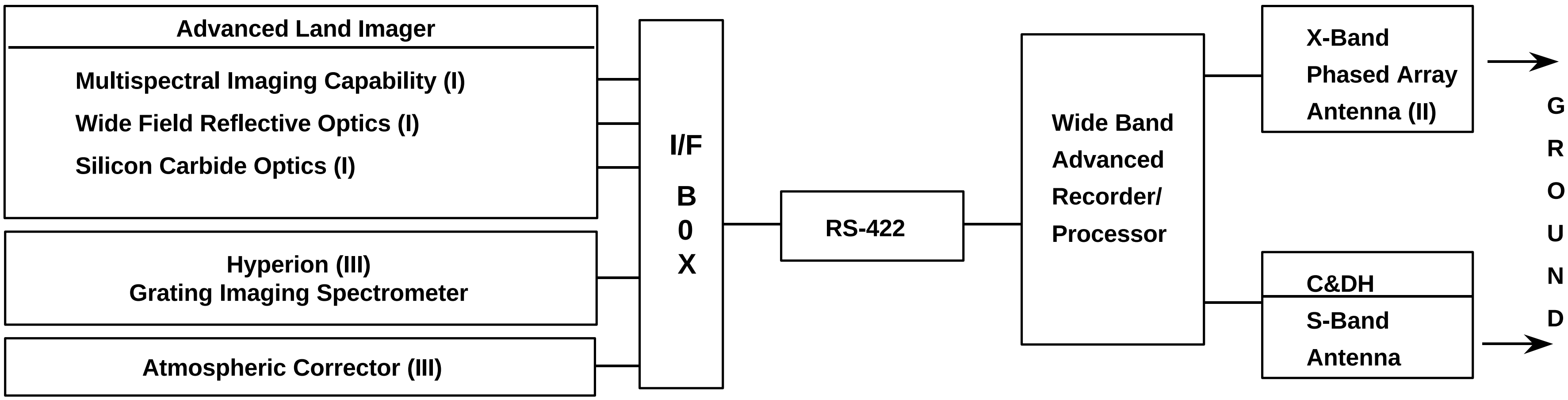
EO-1 and Landsat

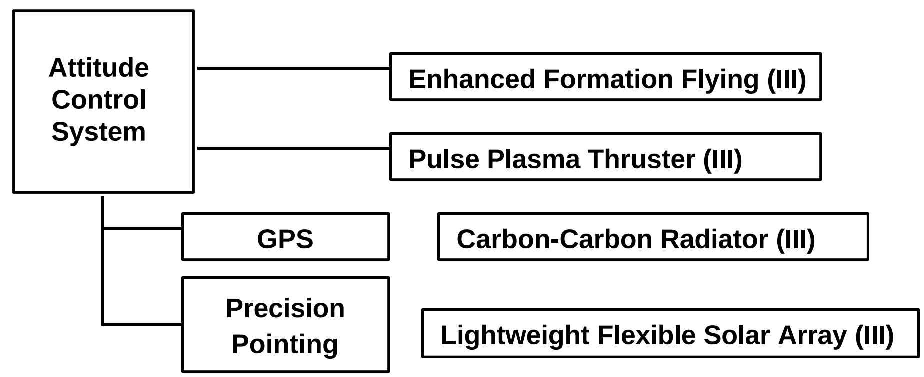


EO-1 and Landsat 7 Descending Orbit Ground Tracks



EO-1 Technologies



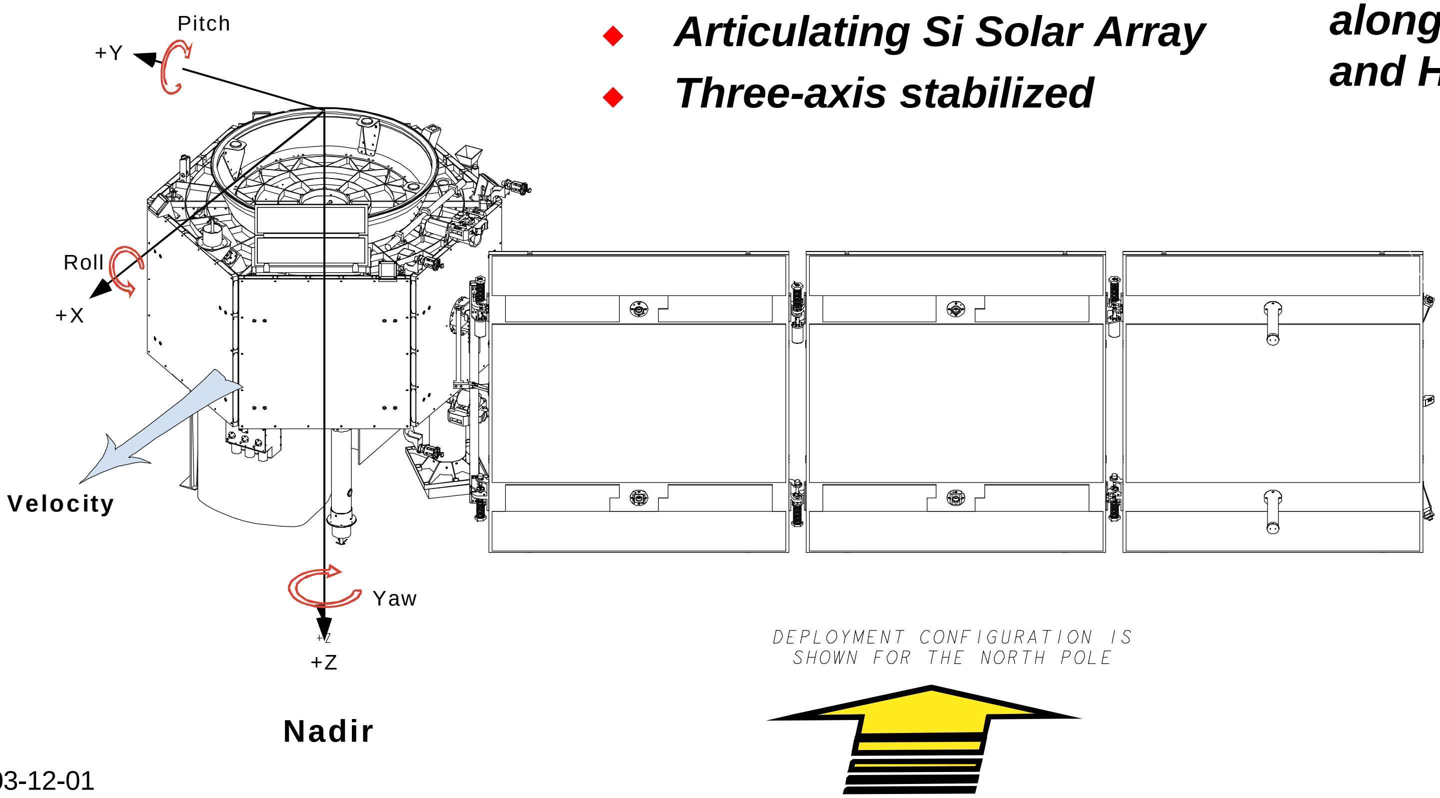


EO-1 TECHNOLOGIES

- *Multispectral Imaging Capability*
- *Wide Field Reflective Optics*
- *Silicon Carbide Optics*
- *Grating Imaging Spectrometer (HYPERION)*
- *Atmospheric Corrector (AC)*
- *X-Band Phased Array Antenna*
- *Enhanced Formation Flying (EFF)*
- *Pulse Plasma Thruster (PPT)*
- *Carbon-Carbon Radiator (CCR)*
- *Lightweight Flexible Solar Array*
- *Wideband Advanced Recorder / Processor (WARP)*

EO-1 Spacecraft

- ***Power***
  - *315 Watts*
  - *50 Ahr*
  - *Super NiCd*
- ***Data Storage***
  - *Housekeeping: 1 Gbit*
  - *Science: 48 Gbits*
- ***Articulating Si Solar Array***
- ***Three-axis stabilized***
- ***Mass***
  - *588 Kg (562.3 Kg actual)*
- ***Built by Swales Aerospace along with Litton Amecom and Hammers Co.***

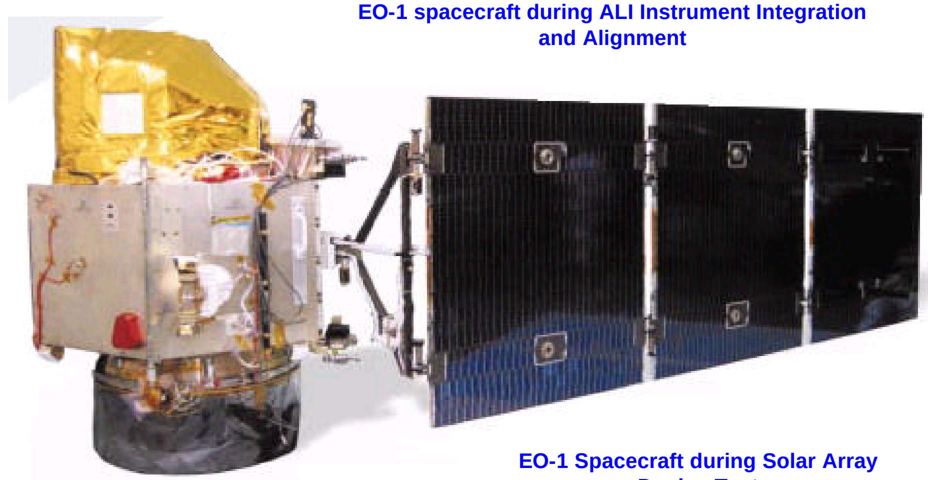


Spacecraft Bus Development

EO-1 Functional Test & Software Development Area Adjacent to Swales I&T Cleanrooms and Laboratories in Beltsville, MD.

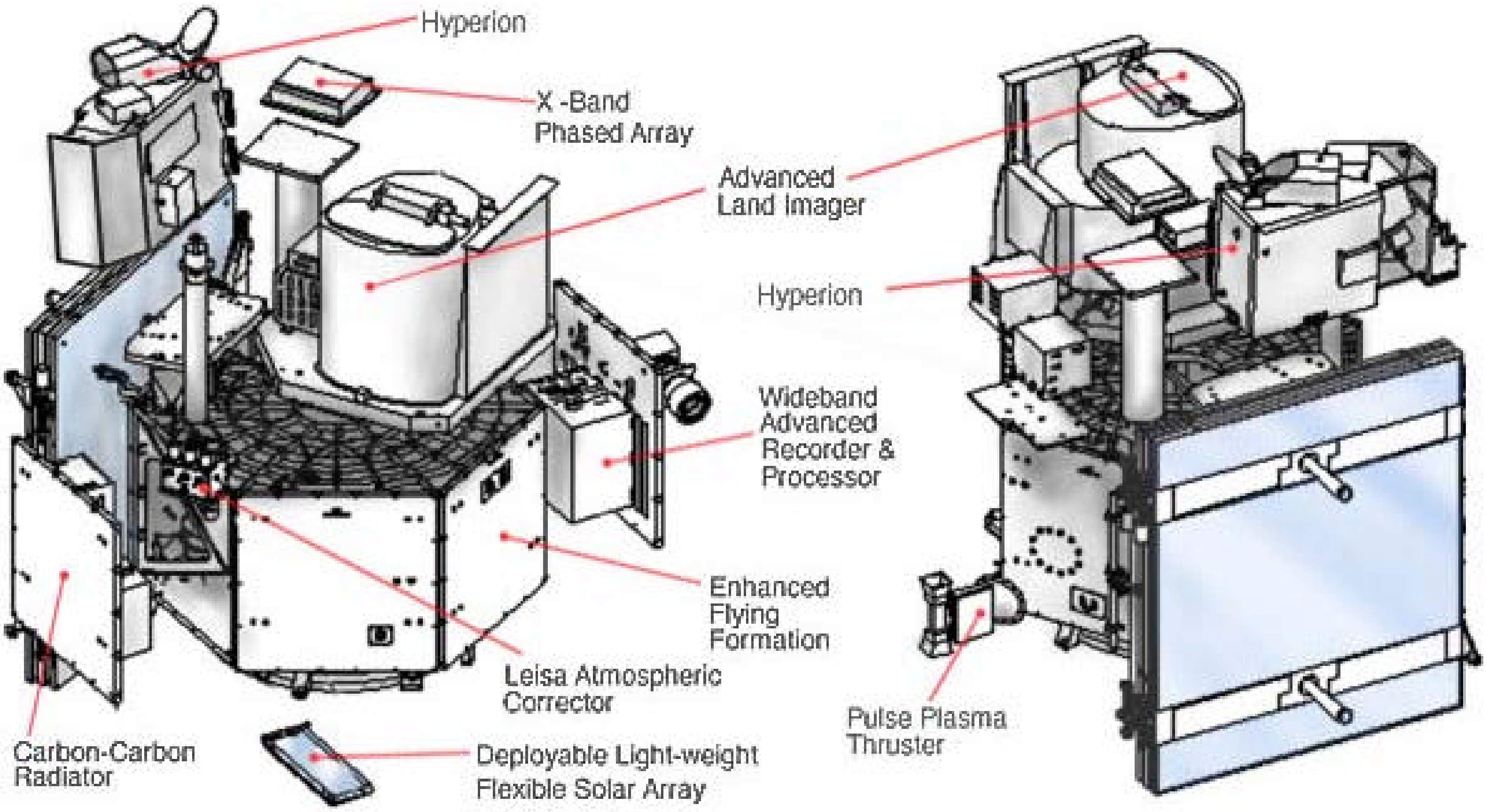
EO-1 spacecraft during ALI Instrument Integration and Alignment

Swales Managed and Staffed Satellite Launch Vehicle Interface and Launch Site Ops. at VAFB



EO-1 Spacecraft during Solar Array Deploy Test

EO-1 Technology Locations



Mission Characteristics

Mission Design Life: *18 months*

Nominal Life: *12 months*

LAUNCH

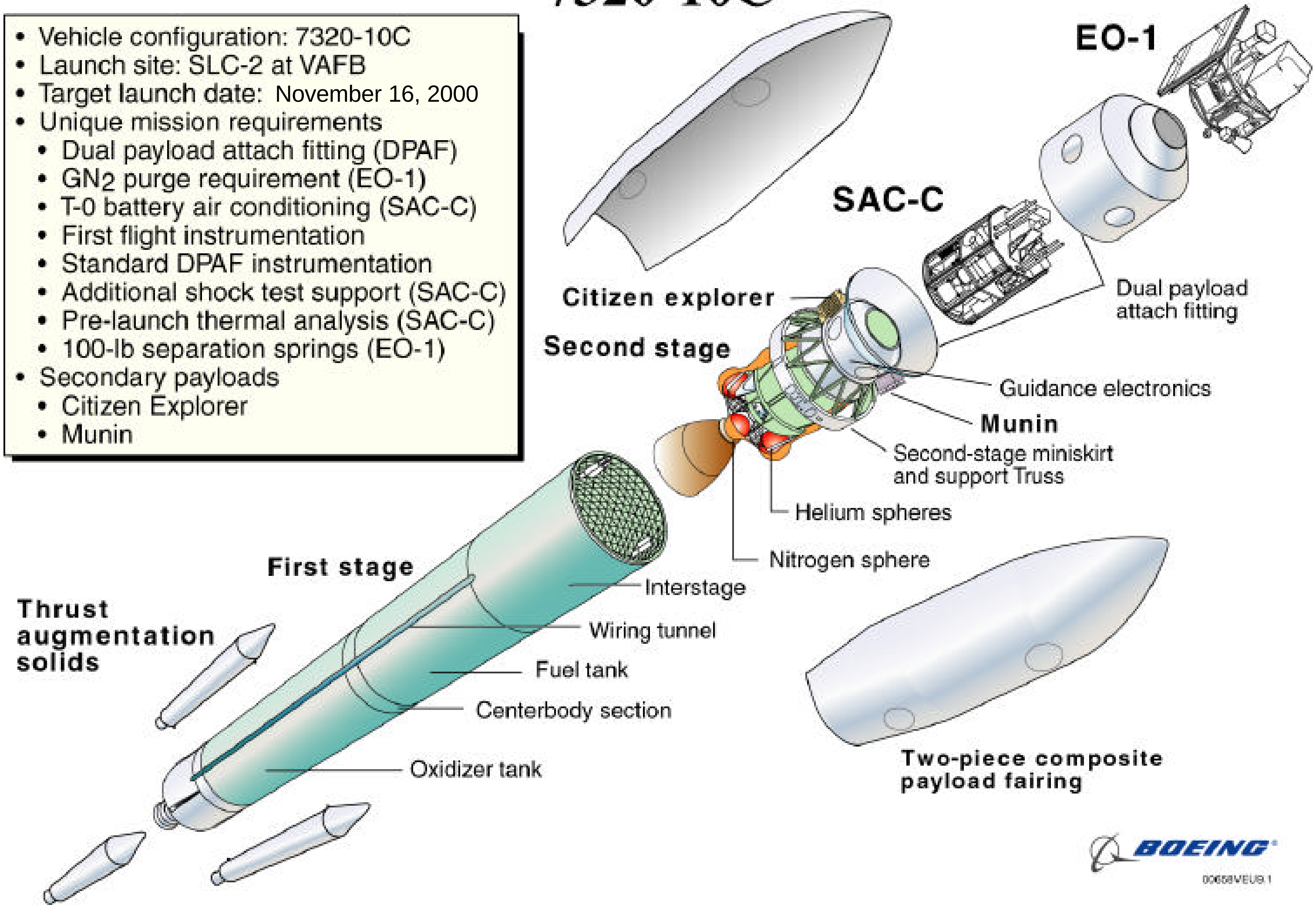
- **Date:** *11/21/00*
- **Time:** *10:24 p.m. PST*
- **Window:** *10 seconds*
- **Site:** *Vandenberg AFB (SLC-2)*
- **Launch Vehicle:** *Delta II DPAF Mission with SAC-C and 1 secondary payload*

ORBIT

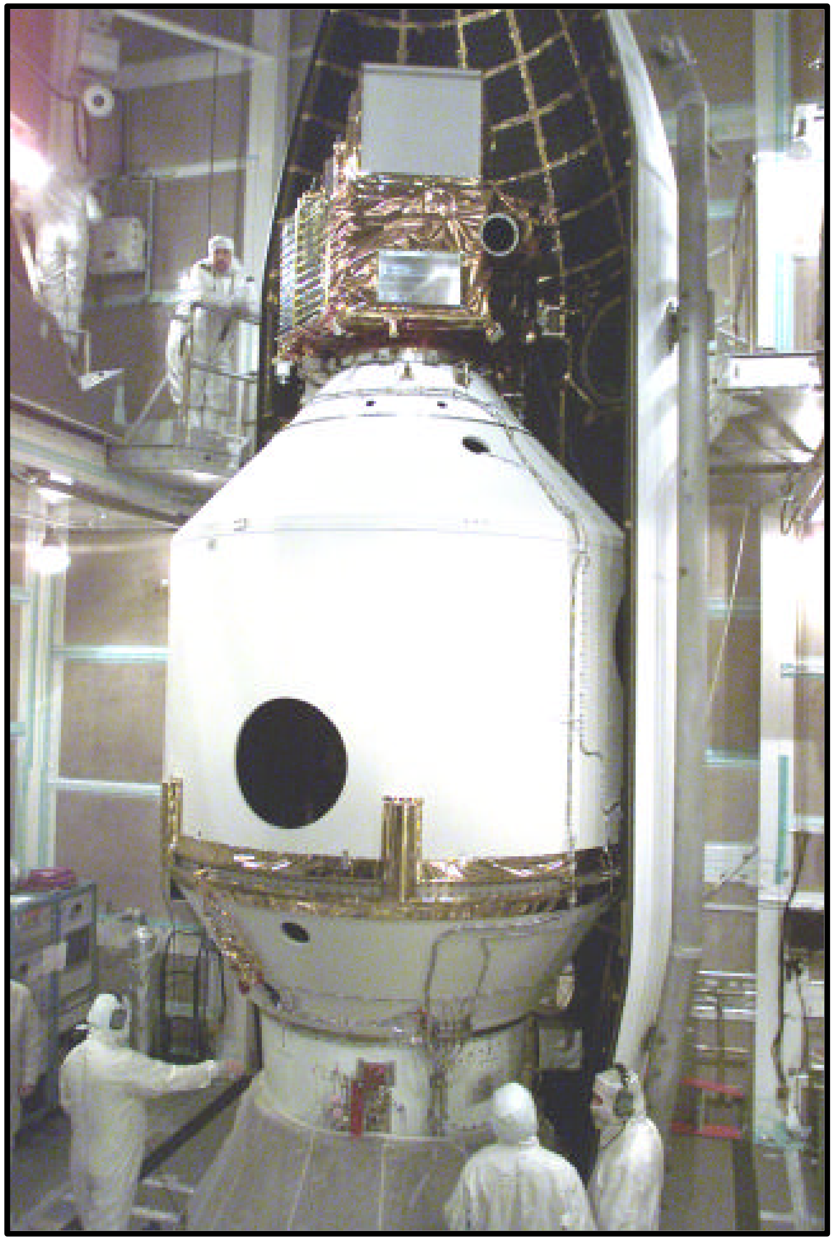
- **Equatorial Crossing Time:** *10:03 a.m., descending node*
- **Altitude:** *705 Km*
- **Inclination:** *98.2°*
- **Orbital Period:** *98 minutes*

Vehicle Configuration Overview
7320-10C

- Vehicle configuration: 7320-10C
- Launch site: SLC-2 at VAFB
- Target launch date: November 16, 2000
- Unique mission requirements
  - Dual payload attach fitting (DPAF)
  - GN_2 purge requirement (EO-1)
  - T-0 battery air conditioning (SAC-C)
  - First flight instrumentation
  - Standard DPAF instrumentation
  - Additional shock test support (SAC-C)
  - Pre-launch thermal analysis (SAC-C)
  - 100-lb separation springs (EO-1)
- Secondary payloads
  - Citizen Explorer
  - Munin



Spacecraft on DPAF



Spacecraft on DPAF

Integrated Spacecraft

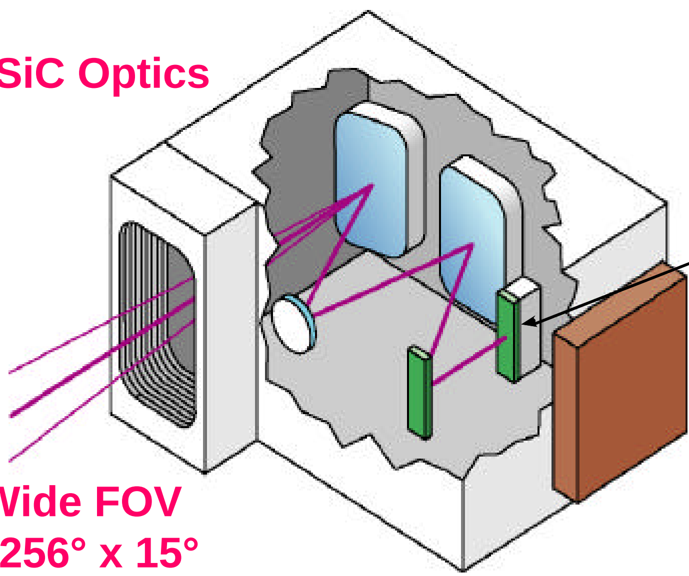
Spacecraft on Delta

Advanced Land Imager (ALI)

- ***ALI is an instrument incorporating several new technologies that promise better, lower cost performance for future Landsat missions***
  - *The relatively warm operating temperature of the HgCdTe detectors enables passive cooling of the focal plane which greatly simplifies instrument operation*
- ***ALI was designed, assembled, environmentally tested and calibrated by the MIT Lincoln Laboratory***
  - *The Focal Plane System was supplied by Raytheon/ SBRS*
  - *The telescope was supplied by SSG Inc*

Advanced Land Imager (ALI)

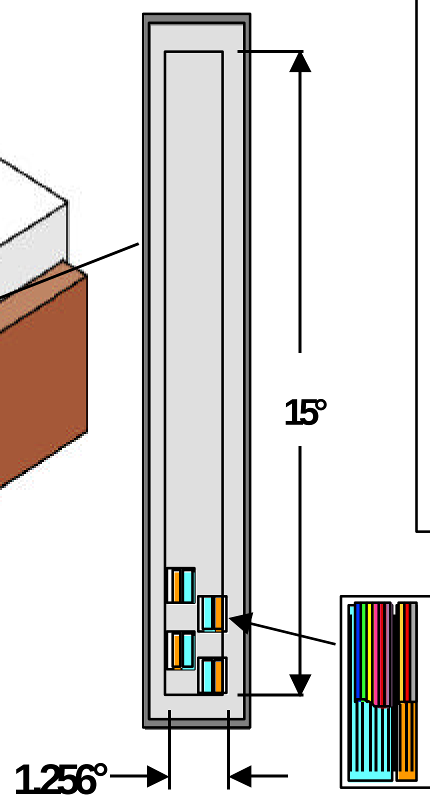
SiC Optics



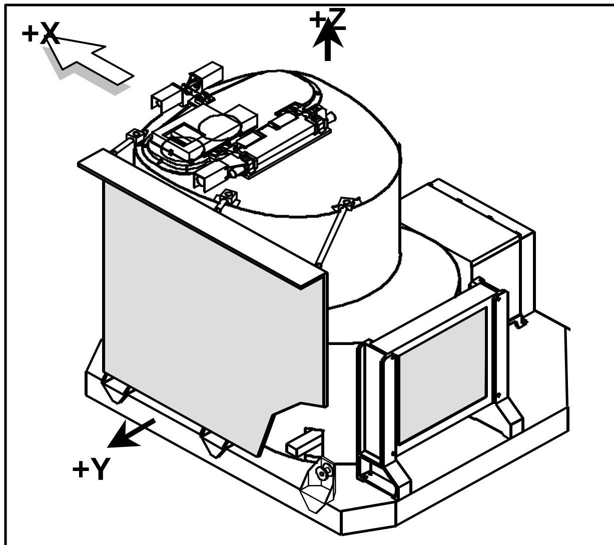
Wide FOV
1.256° x 15°

Band	Ground Sampling
Pan	10 m
MS	30 m

Main Focal Plane Assembly

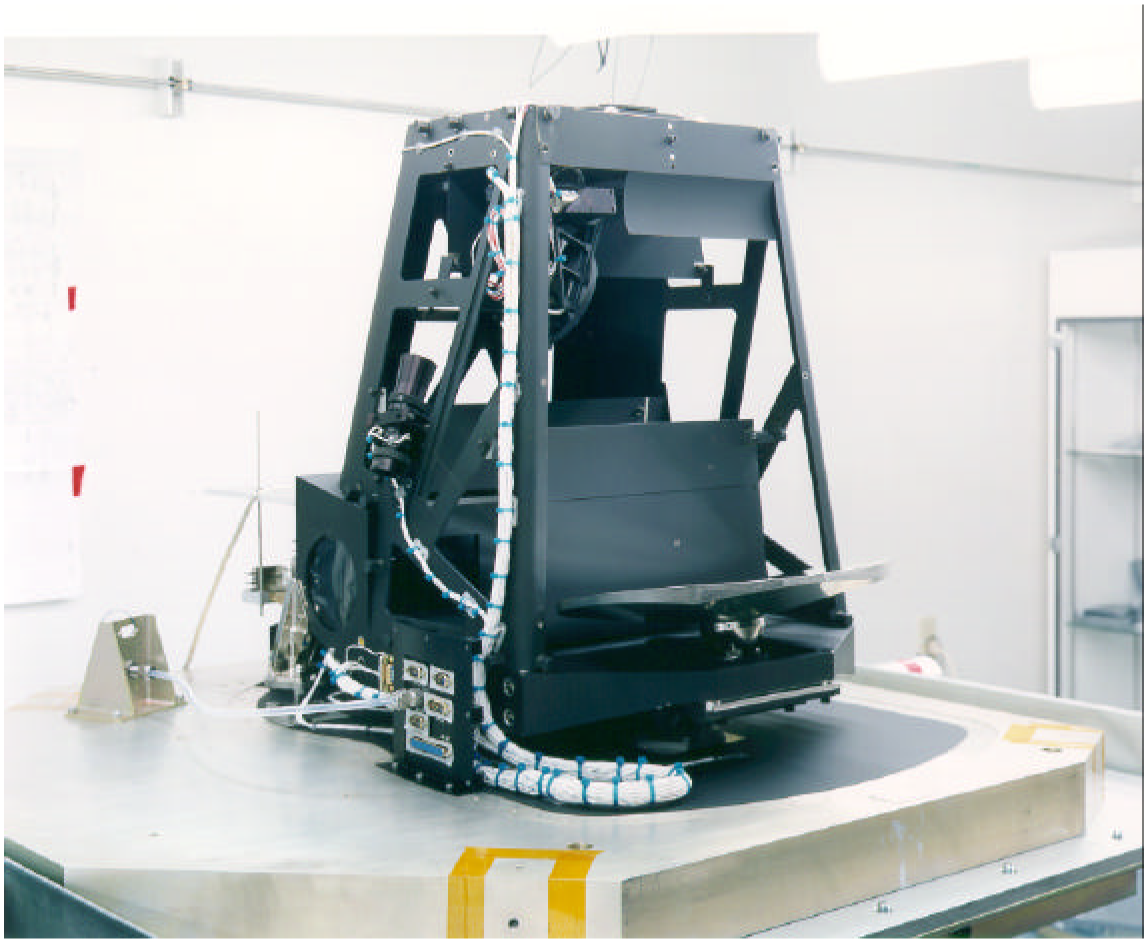


Multispectral/
Panchromatic
6 VNIR + 3 SWIR
220 K



ALI Without MLI

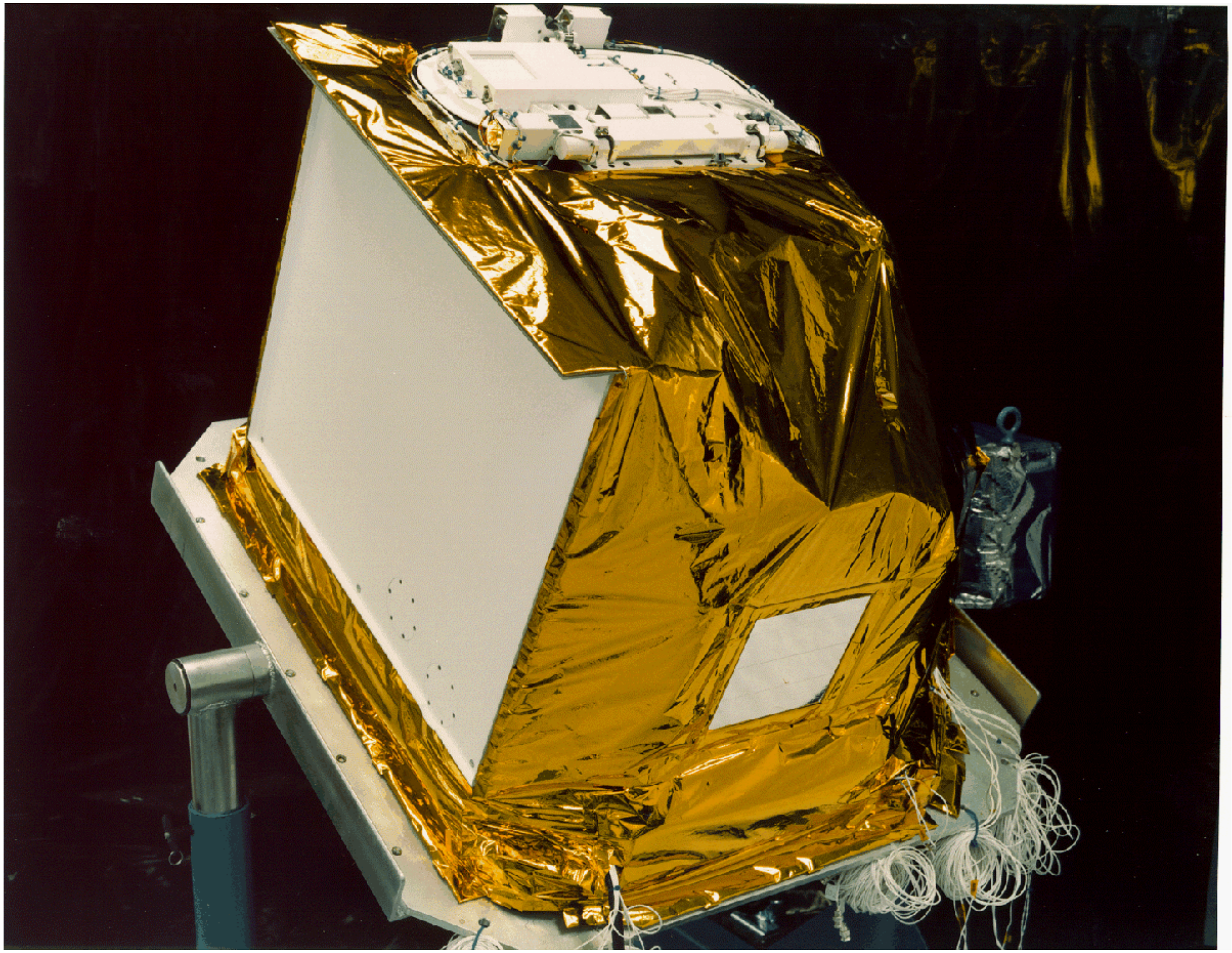
Partially Assembled Flight ALI



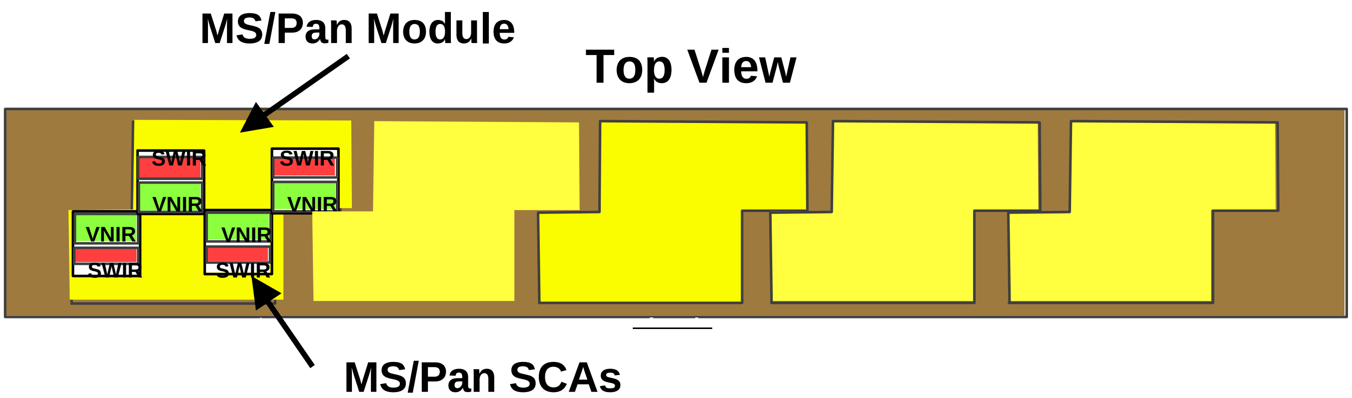
Telescope features

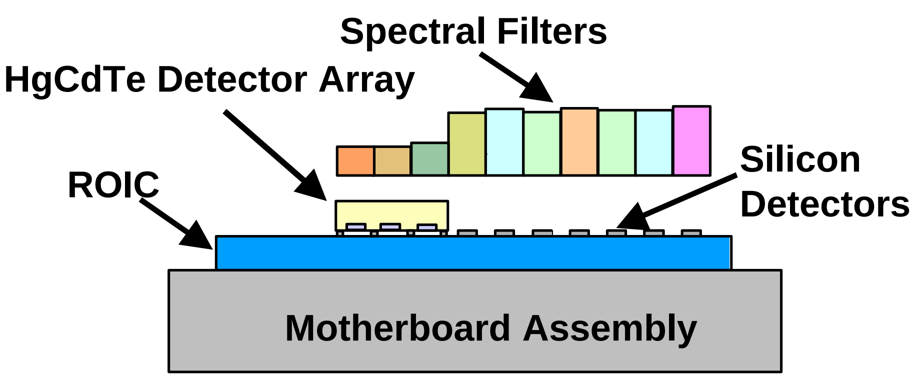
- ***12.5 cm entrance pupil***
- ***15° x 1.26° field-of-view***
- ***Telecentric, f/7.5 design***
- ***Unobscured, reflective optics***
- ***Silicon carbide mirrors***
- ***Wavefront error = 0.11 l RMS @ 633 nm***

Full Dressed Picture of ALI



Main Focal Plane Assembly

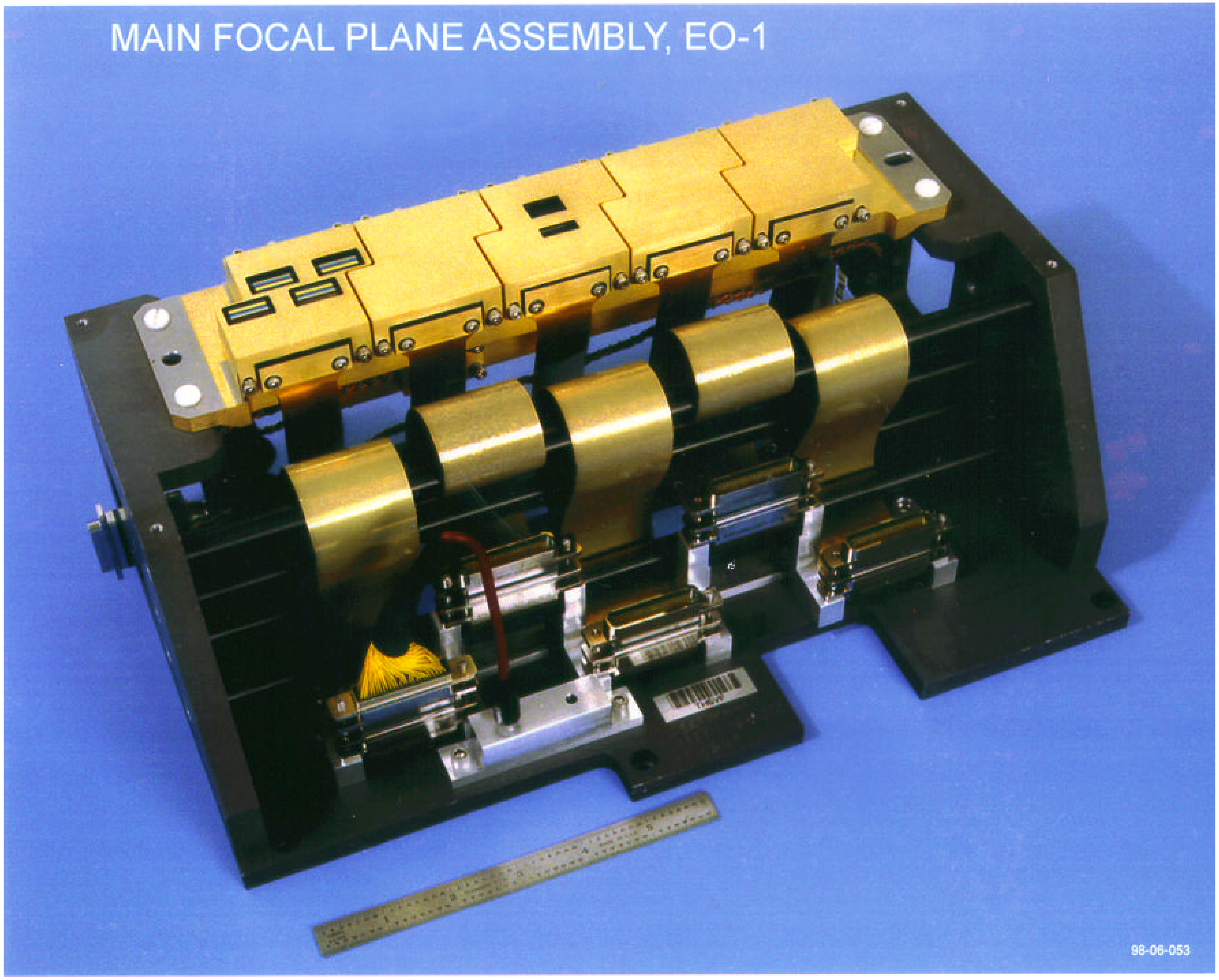




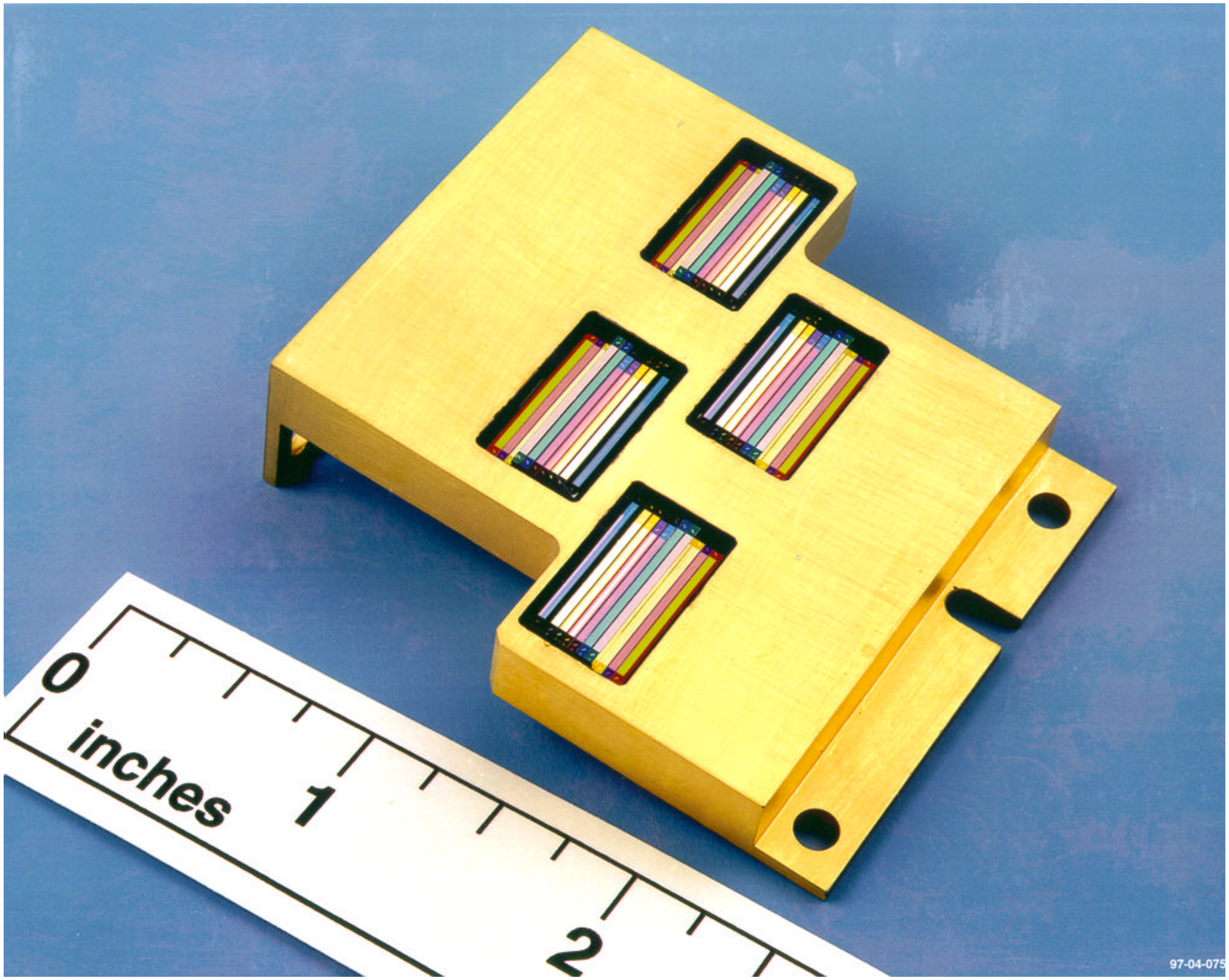
MS/Pan SCA

MS : Multispectral
Pan : Panchromatic
ROIC : Read-out Integrated Circuit
SCA : Sensor Chip Assembly
SWIR : Short Wave Infrared
VNIR : Visible Near Infrared

ALI Focal Plane Assembly



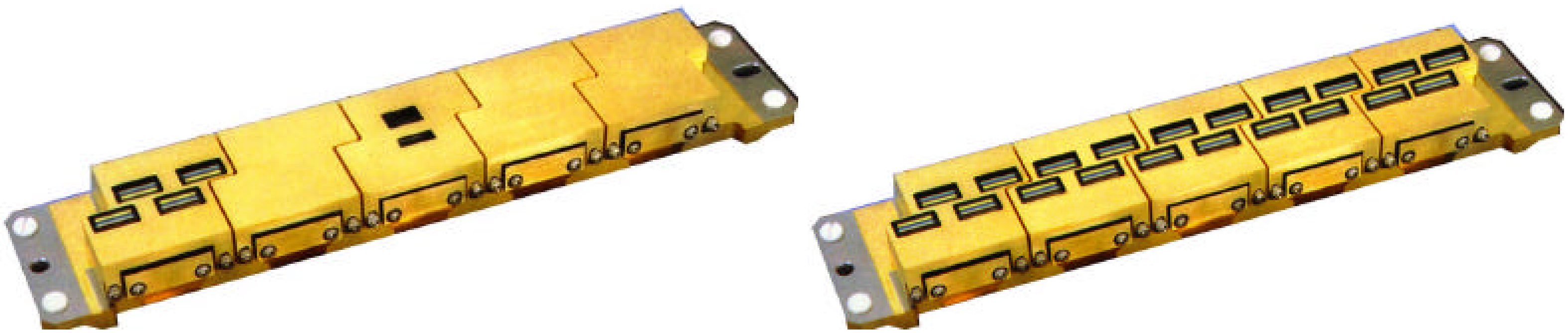
MS/PAN Flight Module



Growth Path to Operational Instrument

Populate focal plane with 5 MS/PAN modules

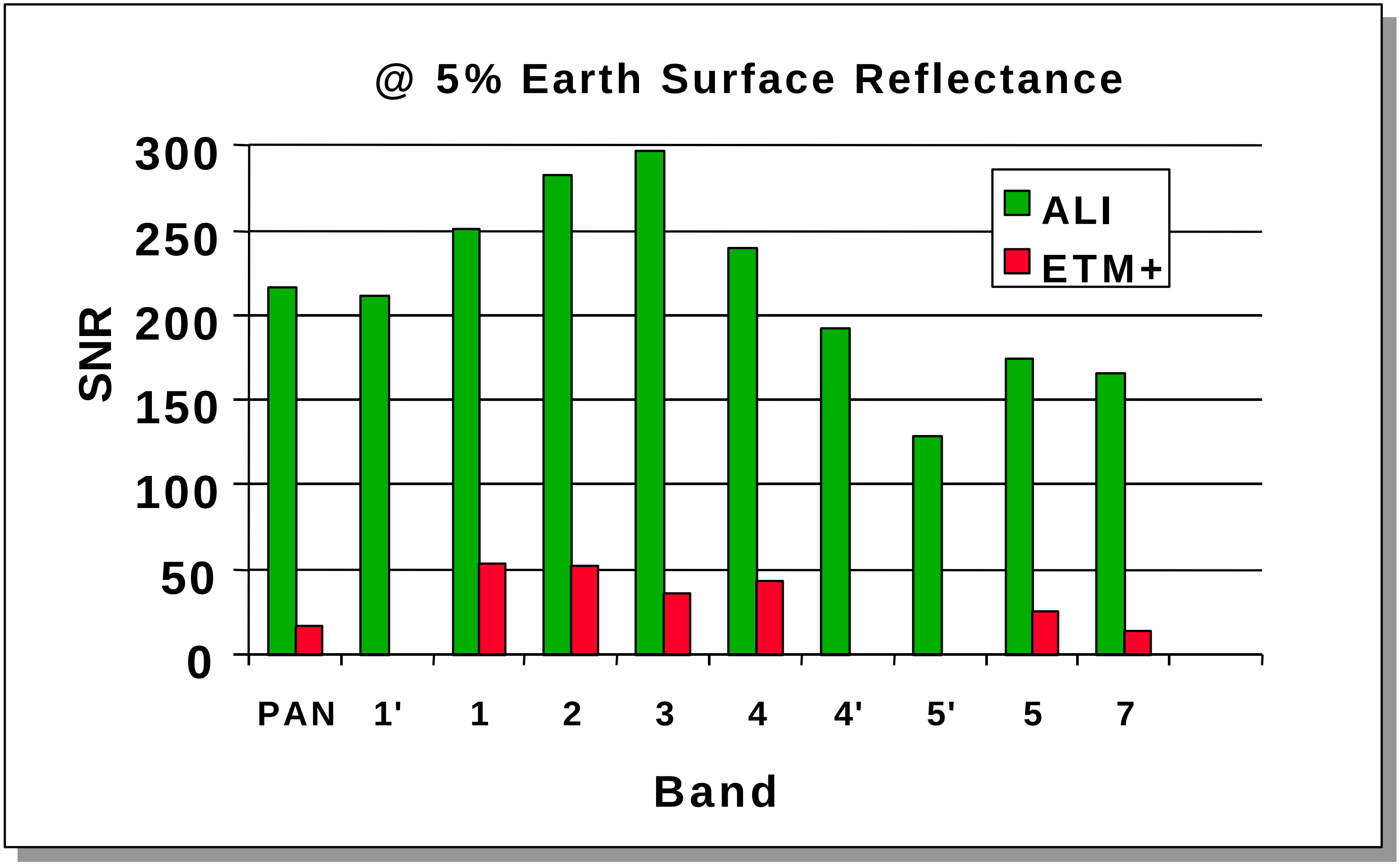
- ❑ Full 185 km wide field-of-view
- ❑ Main Focal Plane bench designed for 5 modules



Changes required to accommodate full MS/PAN coverage

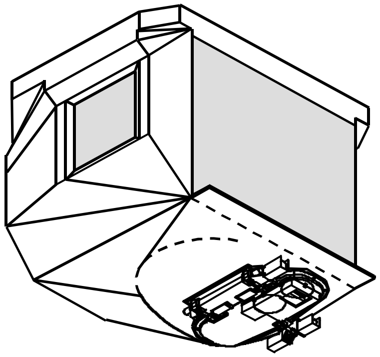
Resource	*ALI*	*Advanced Landsat*
➢ Data Ports	1	5
➢ Data Rate	102.4 Mb/s	512 Mb/s
➢ FPE Power	~ 15 Watts	~ 50 Watts
➢ FPA Size	30.7 x 6.6 x 5.2 cm	30.7 x 6.6 x 5.2 cm

ALI SNR Performance

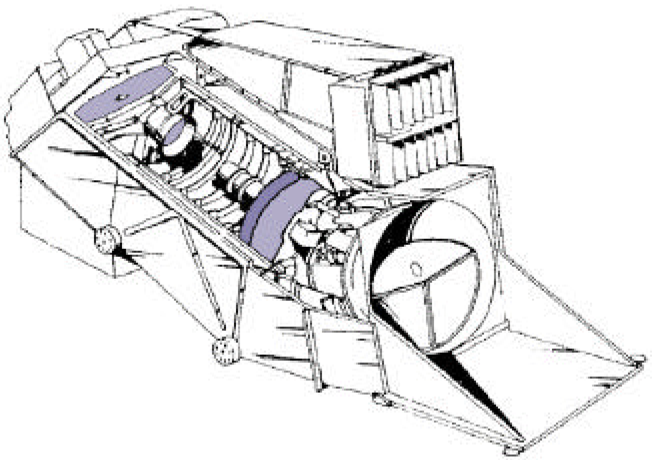


Land Imaging Instrument Comparison

ALI - Concept for Future Landsat Instrument



Enhanced Thematic Mapper (ETM+)

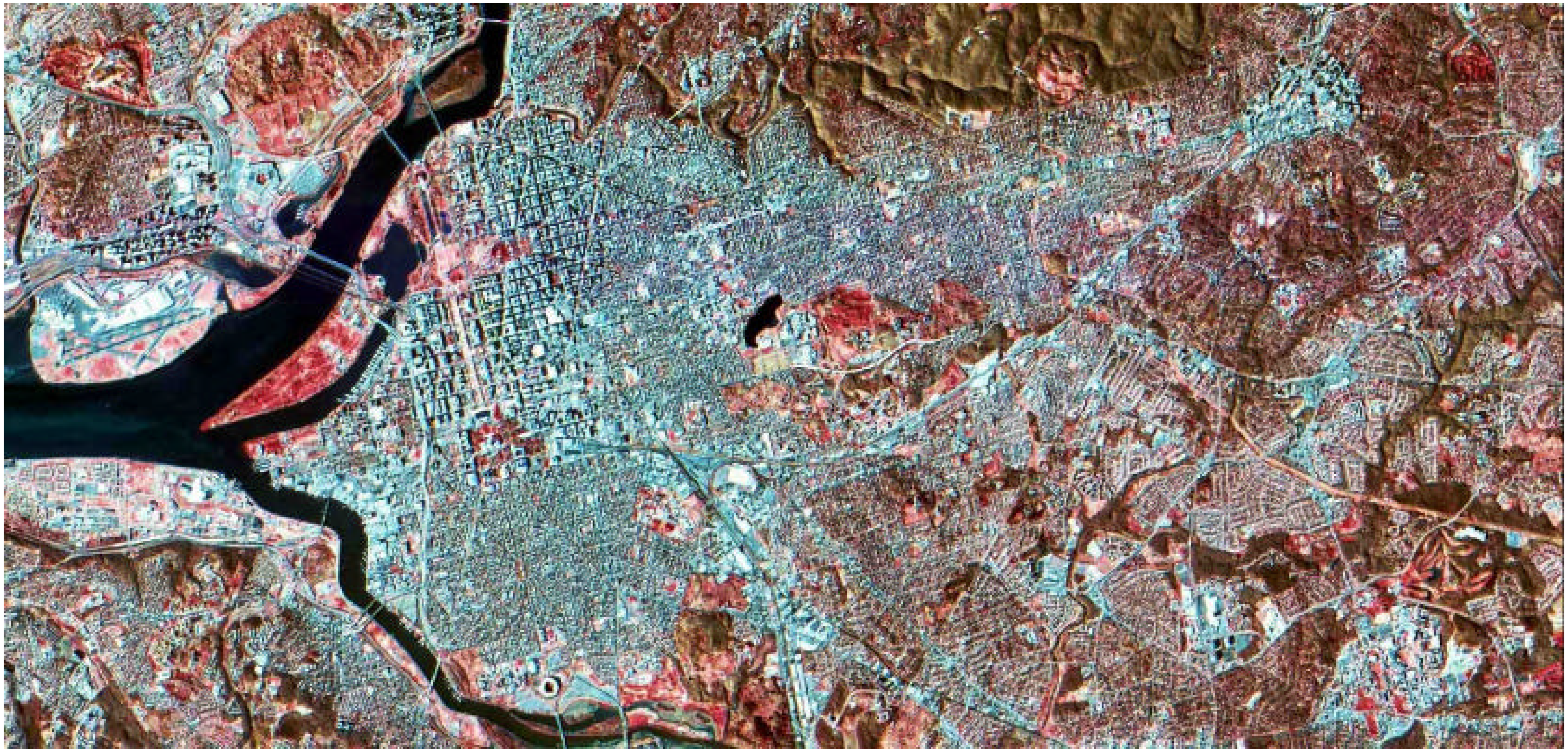


ALI		ETM+
100	Mass (kg)	425
100	Power (W)	545
70 × 75 × 75	Size (cm)	196 × 114 × 66
7, 3, 0	VNIR, SWIR, LWIR Bands	5, 2, 1
10, 30	Pan, MS Resolution (m)	15, 30
4-10	Relative SNR	1

Washington, DC

(2000:356, MS 4-3-2)

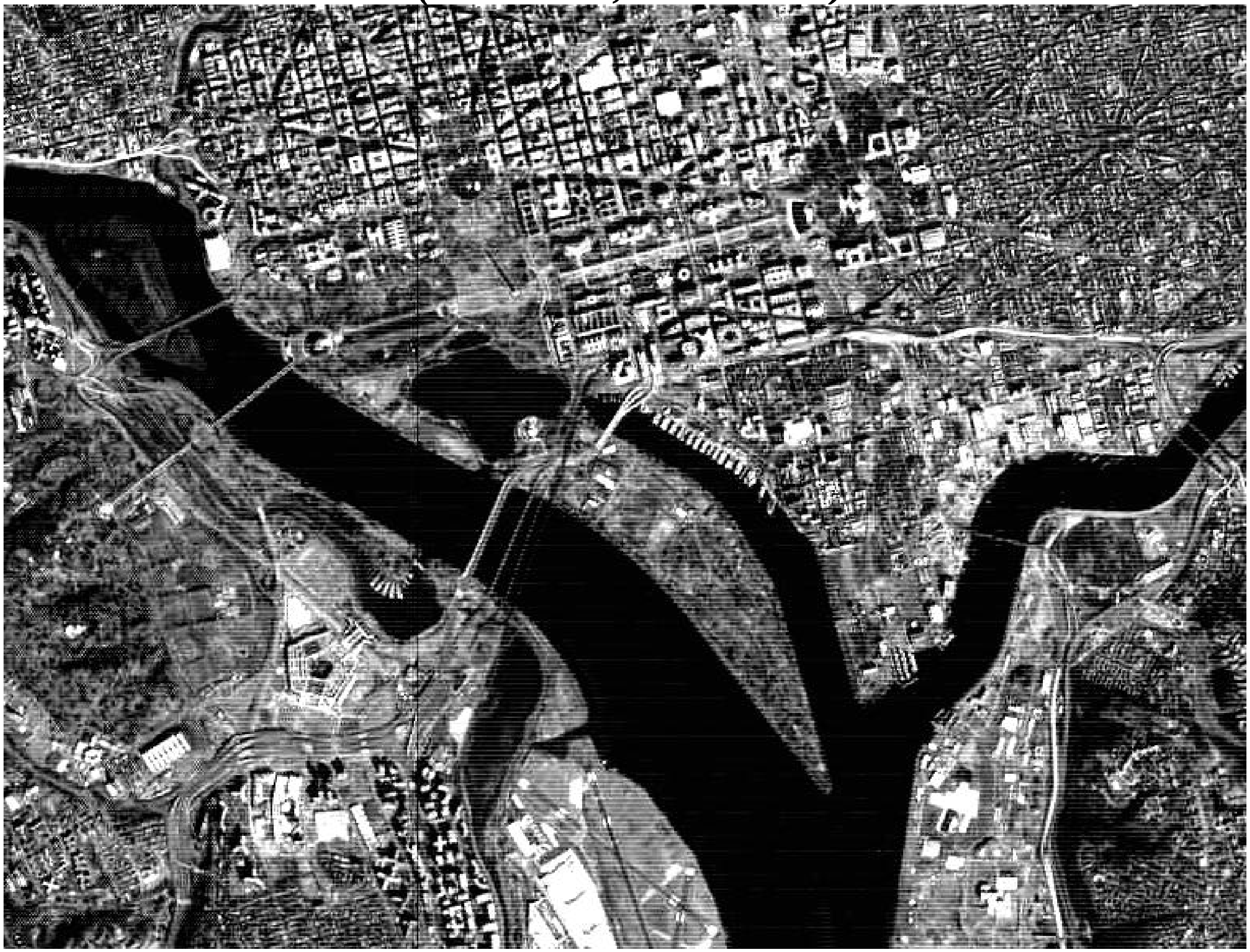
N



Washington, DC

(2000:336, Pan zoom)

N



Oahu,HI

(2000:354, MS 3-2-1)

N

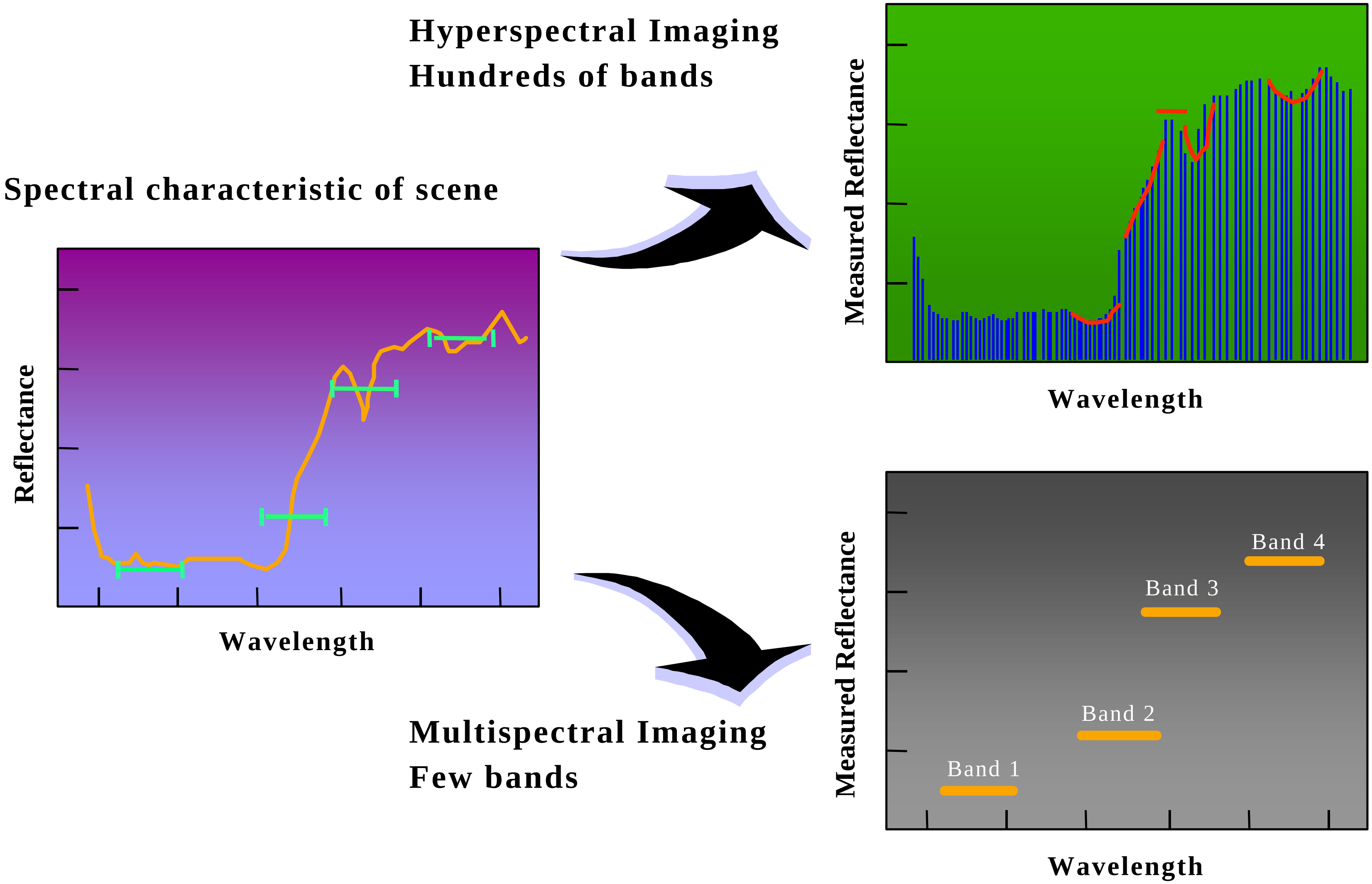
Hyperion

- ***The Hyperion instrument on EO-1 is the first hyperspectral imager in space, demonstrating this new technology***
  - ***Hyperion will set the standard for hyperspectral imagery, enabling NASA to establish minimum requirements for future data buy***
- ***Hyperion FOV is coaligned with ALI's active area to enable cross-calibration of earth scenes with complete spectrum***
  - ***Discrete channels on Landsat and ALI can be checked with Hyperion***
  - ***Comparison with Terra MODIS and ASTER also planned***
- ***Hyperion satisfies NASA's desire to replace the Hyper-Spectral Imager (HSI) that was lost with the Lewis mission.***
  - ***This new technology can provide unique insight into many scientific and commercial disciplines***

Hyperspectral Imaging Applications & Benefits

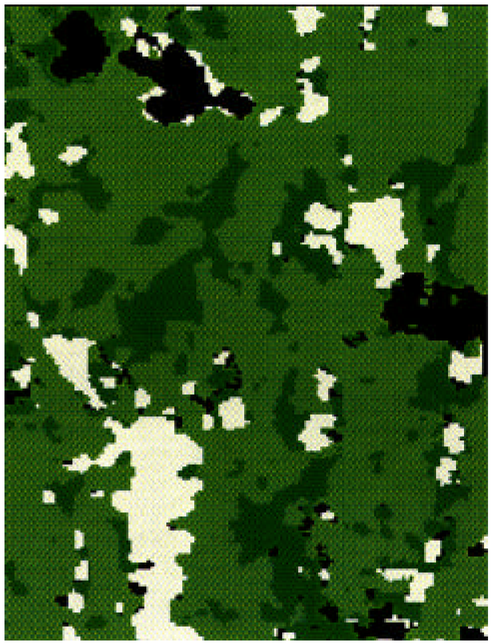
Application	LandSat Capability	Hyperion Capability	Perceived Benefits
Mining/Geology	Land cover classification	Detailed mineral mapping	Accurate remote mineral exploration
Forestry	Land cover classification	Species ID Detail stand mapping Foliar chemistry Tree stress	Forest health/infestations Forest productivity/yield analysis Forest inventory/harvest planning
Agriculture	Land cover classification Limited crop mapping Soil mapping	Crop differentiation Crop stress	Yield prediction/commodities crop health/vigor
Environmental Management	Land use monitoring	Chemical/mineral mapping & analysis	Contaminant Mapping Vegetation Stress

Hyperspectral and Multispectral Scene Characterization



Hyperspectral Image Provides Forestry Detail

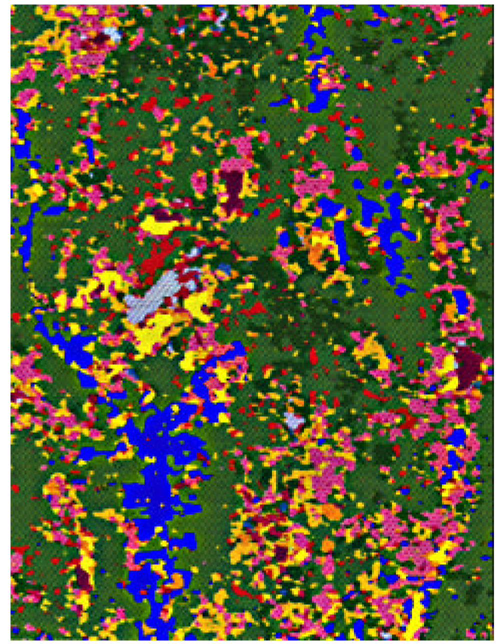
LandSat Analysis



Legend

- No Data
- Hardwood
- Softwood
- Grass / Fields

Hyperspectral Analysis



Legend

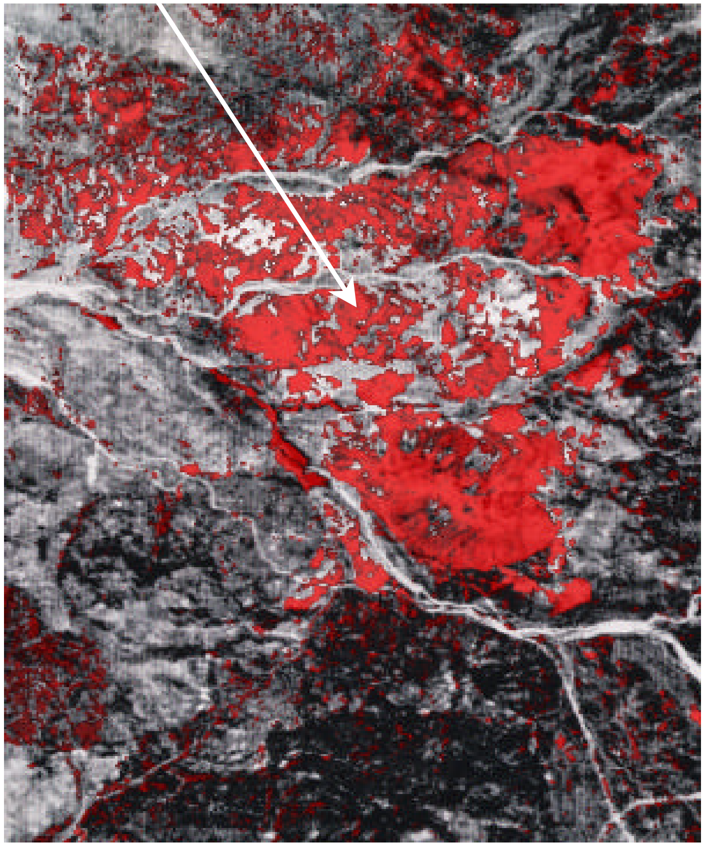
- No Data Open field
- Red Maple
- Red Oak
- Mixed Hardwood
- Hardwood/ Conifer Mix
- White Pine
- Hemlock/ Hardwood Mix
- Mixed Conifer
- Norway Spruce
- Red Pine
- Spruce Swamp
- Hardwood Bog

Analysis by Mary Martin University of New Hampshire

Hyperspectral Image Provides Geological Data

GEOTHERMAL AREA

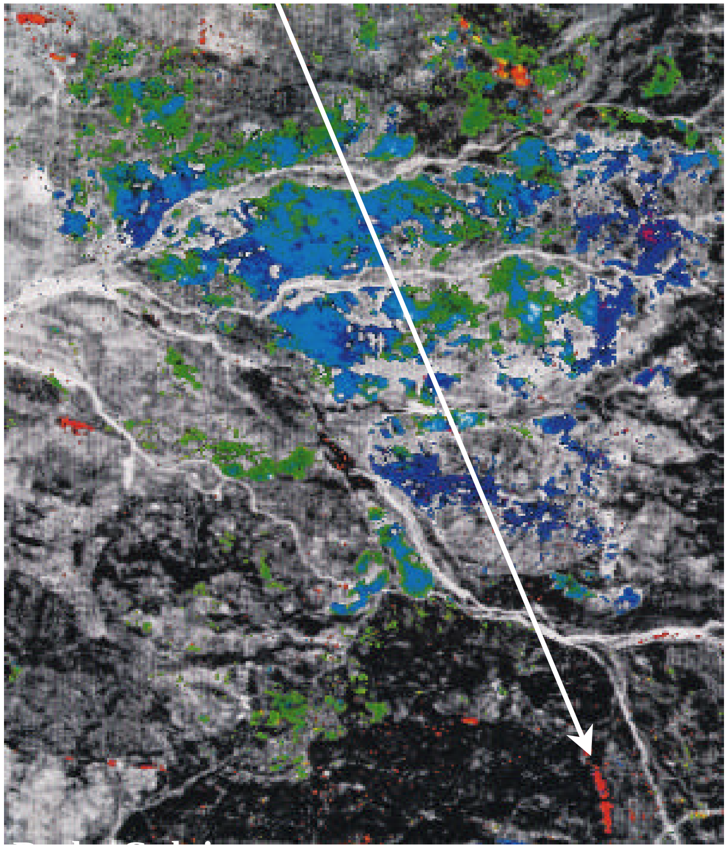
(no specific mineral information)



MULTISPECTRAL ANALYSIS

CALCITE

(gold bearing quartz)



HYPERSPECTRAL ANALYSIS

Analysis courtesy AIG Limited Liability Company

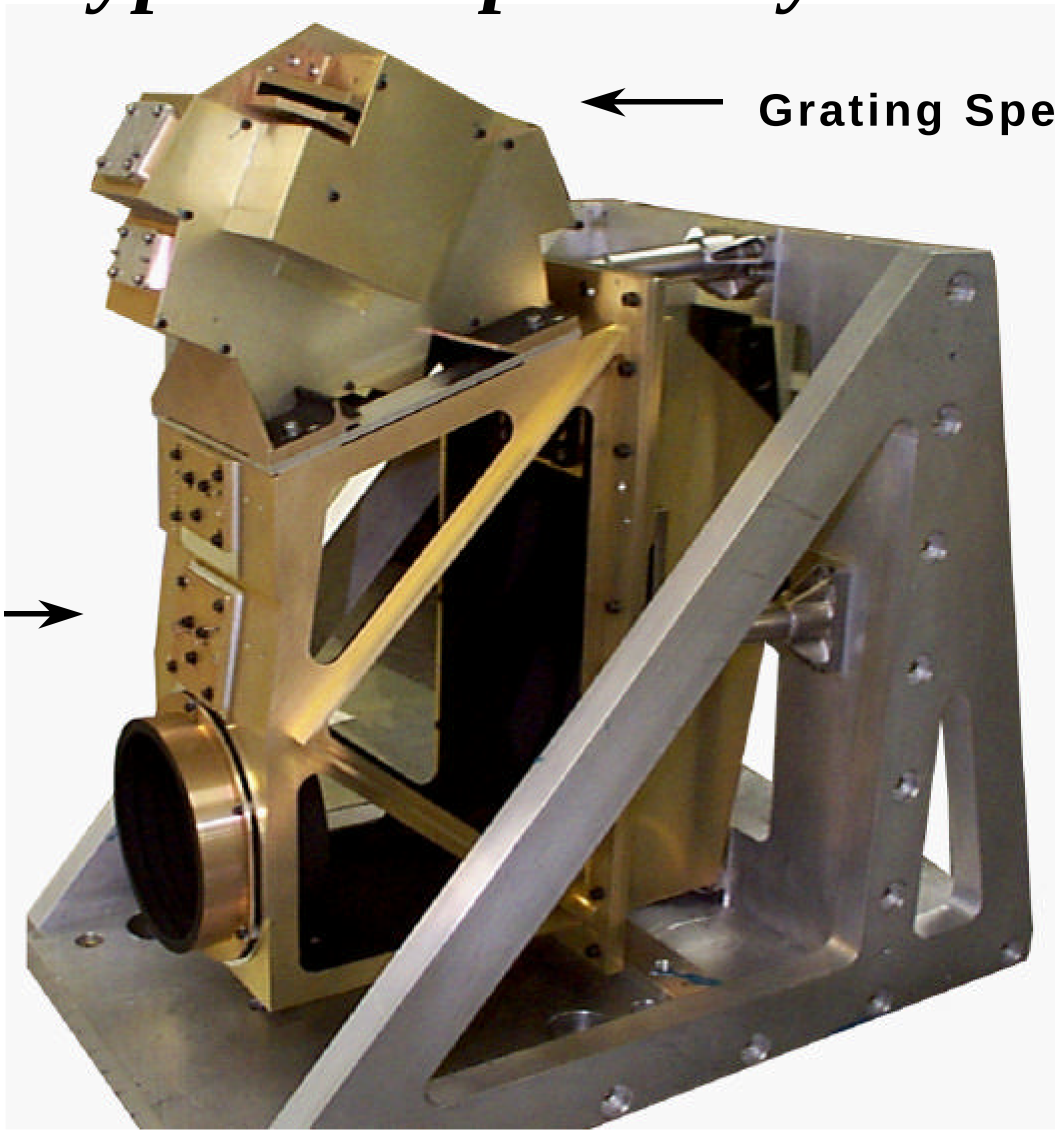
Hyperion Hyperspectral Imager

- *Hyperion is a push-broom imager with:*
  - *220 10 nm bands covering the spectrum from 0.4 mm - 2.5 mm*
  - *6% absolute radiometric accuracy*
  - *Image swath width of 7.5 km*
  - *IFOV of 42.5 mrad*
  - *GSD of 30 m at 705 km altitude*
  - *12-bit image data*
  - *MTF 0.34 - 0.48*
  - *Power: 51W orbit avg., 126W peak*
  - *Mass: 49 kg*

Hyperion Sensor Assembly
before Environmental Test
(5/6/99)

Hyperion
12 months from order to delivery

Hyperion Optical System

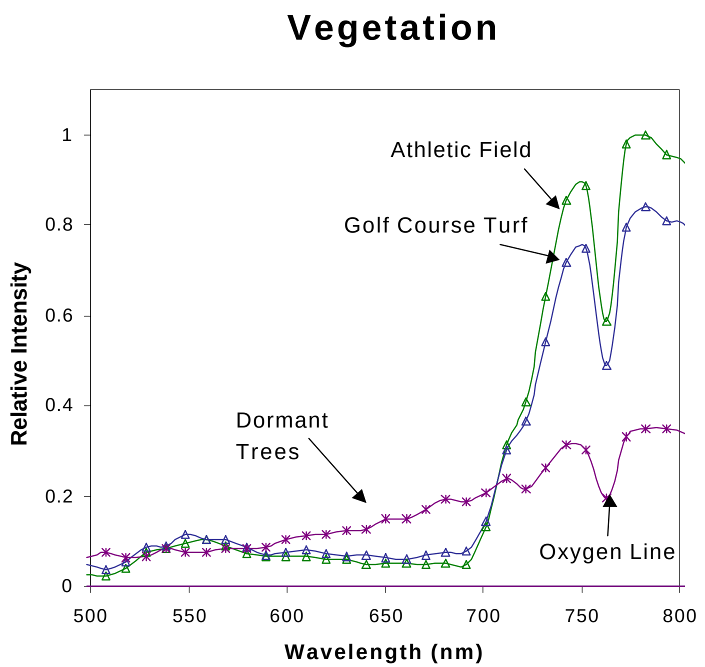


Grating Spectrometer

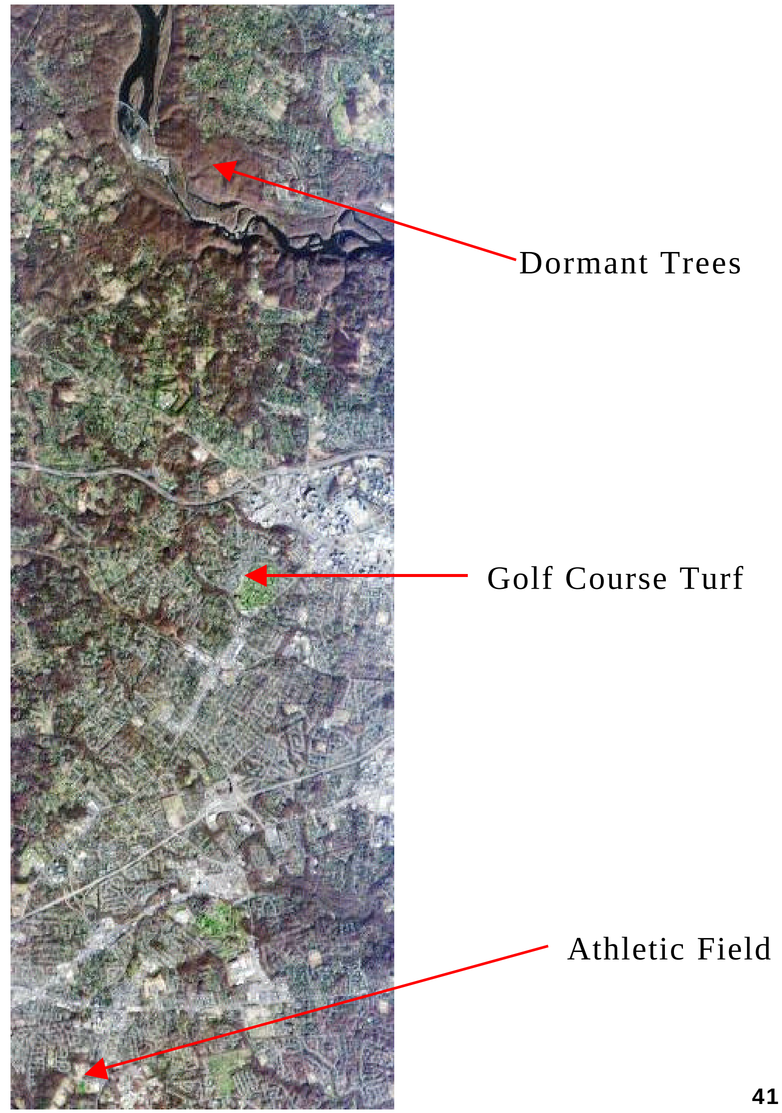
Telescope

Hyperion Image of Fairfax, VA December 2000

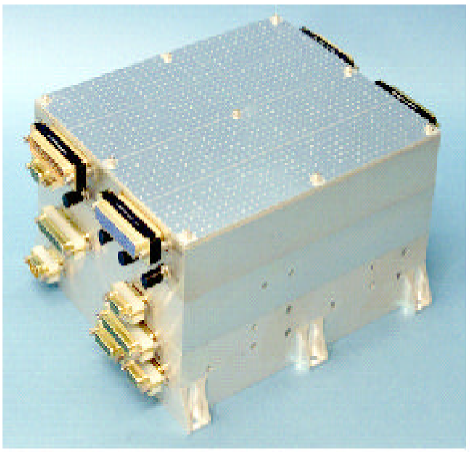
Image taken by Hyperion shows the relative chlorophyll content of vegetation in Fairfax County. The spectral profiles indicate healthy grass in the athletic field and golf course. The spectral profile of the trees indicates dormant vegetation.



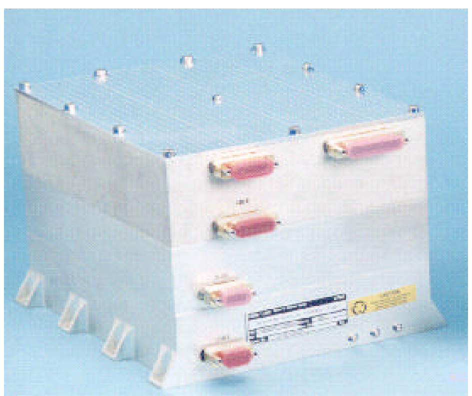
Oxygen in the atmosphere is detected by the spectral profiles in the near infrared wavelength.



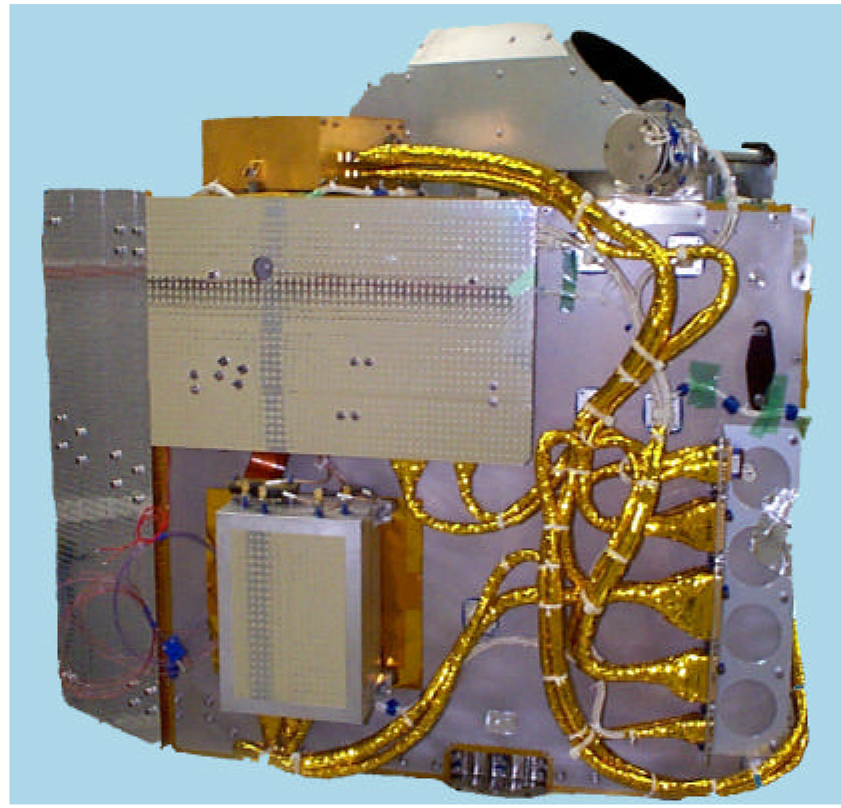
Hyperion Subassemblies



Hyperion Electronics Assembly (HEA)



Cryocooler Electronics Assembly (CEA)



Hyperion Sensor Assembly (HSA)

Late Addition of the Hyperion Instrument

- **Why add the Hyperion?**
  - Both of the NASA Hyperspectral Remote Land Sensing initiatives failed to materialize
    - Small satellite technology initiative Lewis Mission
      - Carried an instrument similar to Hyperion
    - EO-1 Wedge Imaging Spectrometer (WIS) and Grating Imaging Spectrometer (GIS)
  - After a series of studies on how to recover the Hyperspectral Initiative, it was decided to add the Hyperion to the EO-1 mission

How Was It Possible?

- *Robust spacecraft bus design with excess capacity*
- *Use of industry standard electronic bus interfaces; RS 422, CCSDS, 1773*
- *TRW had sufficient critical long lead parts left over from the Lewis mission*
- *Unused resources available from technologies that did not make it*
- *TRW made very experienced people available, many of which had worked on the Lewis instrument*
- *A "can do" team attitude*
- *TRW implemented a very successful Risk Management Plan*

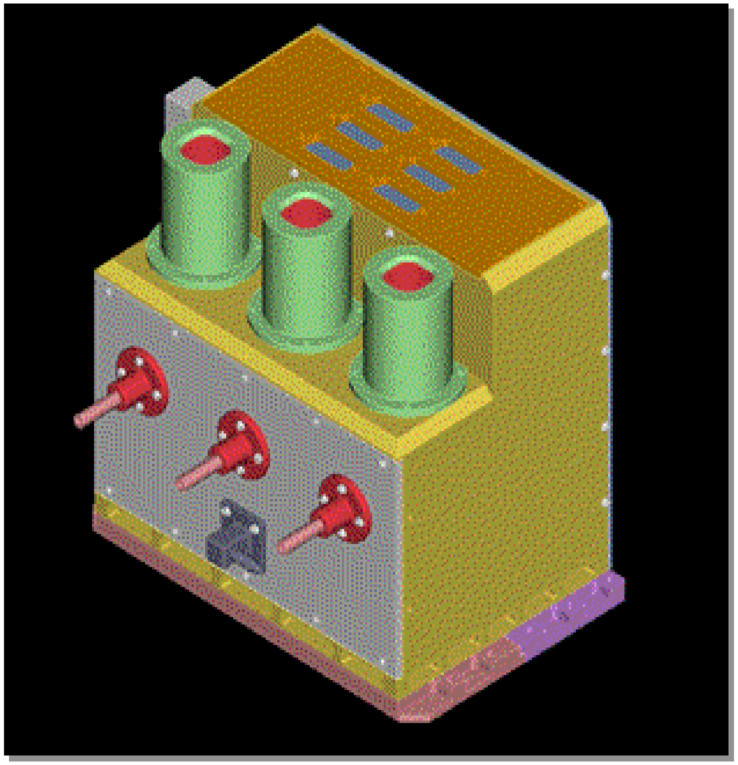
Hyperion Risk Items

Risk Number		WBS Item/Issue	Retired Date
1	G132-004	OMS/ Diffraction Gratings	10/30/98
2	G132-003	OMS/Dichroic Filter	12/4/98
3	G1-001	CEA, HEA, & HITS/Electrical Assembly Personnel	1/19/99
4	G132-001	OMS/GIS Housing	1/19/99
5	G132-005	OMS/Assembly & Test	1/19/99
6	G131-001	Carbon-Carbon Radiator Option	3/4/99
7	G113-001	Cryocooler Mechanical Assembly	3/4/99
8	G112-001	CEA Ripple Filter	5/4/99
9	G112-002	Electronics Parts Availability	5/4/99
10	G121-001	HEA/1553 to 1773 Converter	5/4/99
11	G121-002	HEA/1773 Interface Software	5/4/99
12	G121-003	HEA/Cryocooler Message Handling Software	5/4/99
13	G121-004	HEA/Time Stamp Generation Software	5/4/99
14	G121-005	HEA/Formatter Board	5/4/99
15	G133-001	HITS/New Test Equipment	5/4/99
16	G134-001	Mechanical Loads Response	5/4/99
17	G14-001	Instrument Assembly & Test	6/1/99
18	G132-002	OMS/Mirror Silver Coating	7/7/99

Risk Management Cost Vs. Benefits

- ***Hyperion Project Budget $15 million***
- ***Hyperion Risk Management Costs***
  - *Consultant: $80 K*
  - *Risk mitigation activity: $550 K*
  - *Other labor (estimated): $120 K*
  - *Total expense: $750 K (5%)*
- ***Total number of risk items identified: 18***
  - *Number of handling plans implemented: 12*
  - *Number of risks averted by handling plans: 10*
  - *Value of impacts avoided: $4.75 million!*
  - *Schedule impact avoided: 24 weeks*
- ***How many risks would we need to mitigate to offset the cost impact of risk management? . . . ONE !***

LEISA Atmospheric Corrector



- ***Correct High Spatial Resolution Multispectral Imager Data (ALI and Landsat) for Atmospheric Effects on Surface Reflectance.***
  - *In multispectral images, thin cirrus clouds are not distinguishable from surface reflectance effects. LAC's high spectral resolution allows differentiation between cirrus clouds and surfaces by looking in water vapor absorption bands. Effects may be removed or data flagged*
  - *Atmospheric aerosols and water vapor attenuate light reflected from surface, decreasing apparent surface reflectance. LAC's spectral measurement capability allows simultaneous retrieval of water vapor amounts and estimation of effect on atmospheric transmittance. This may be divided out of multispectral images to obtain true surface reflectance.*

Image of Niger3 (1.243 mm Surface Channel)

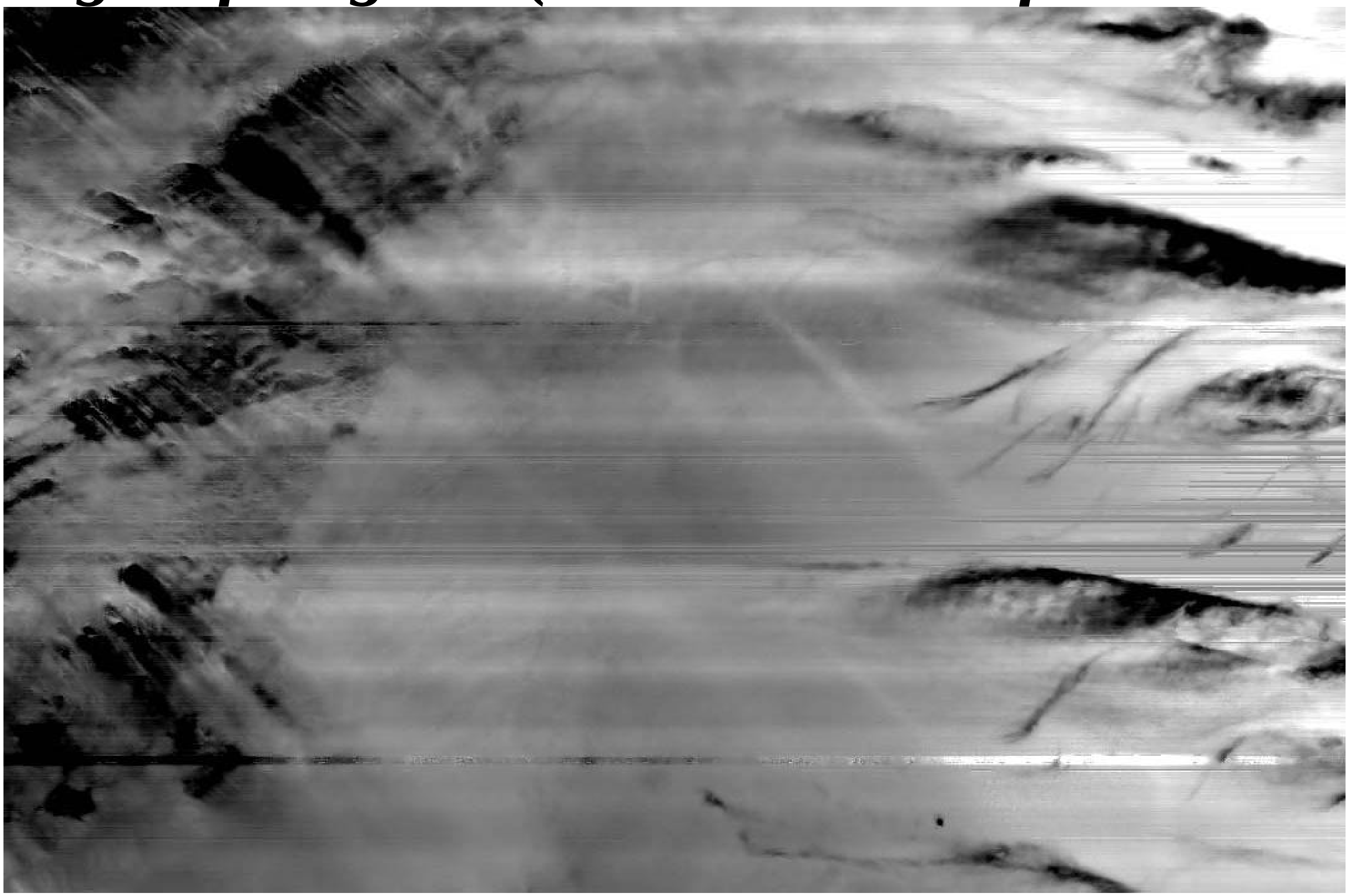
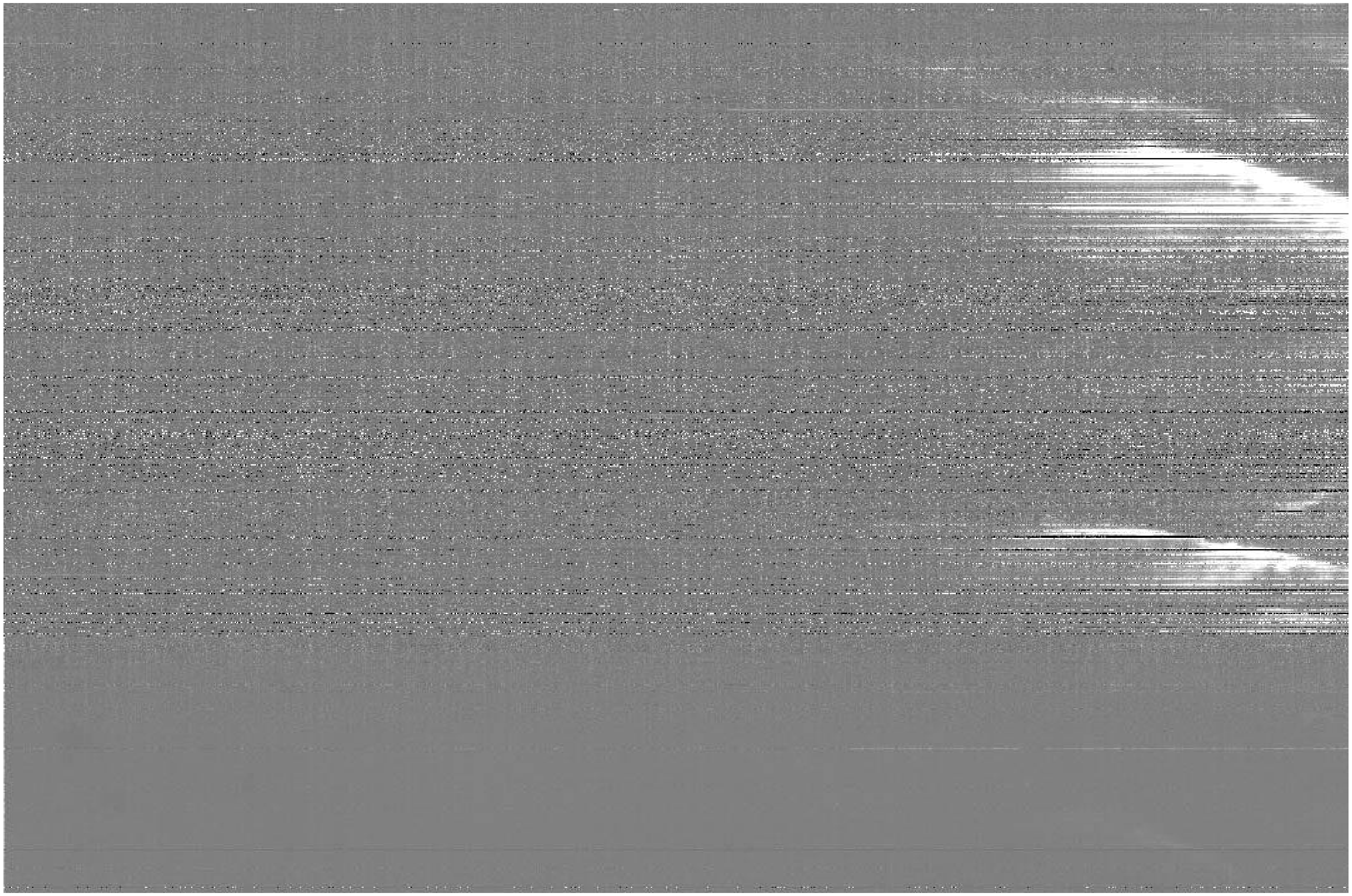
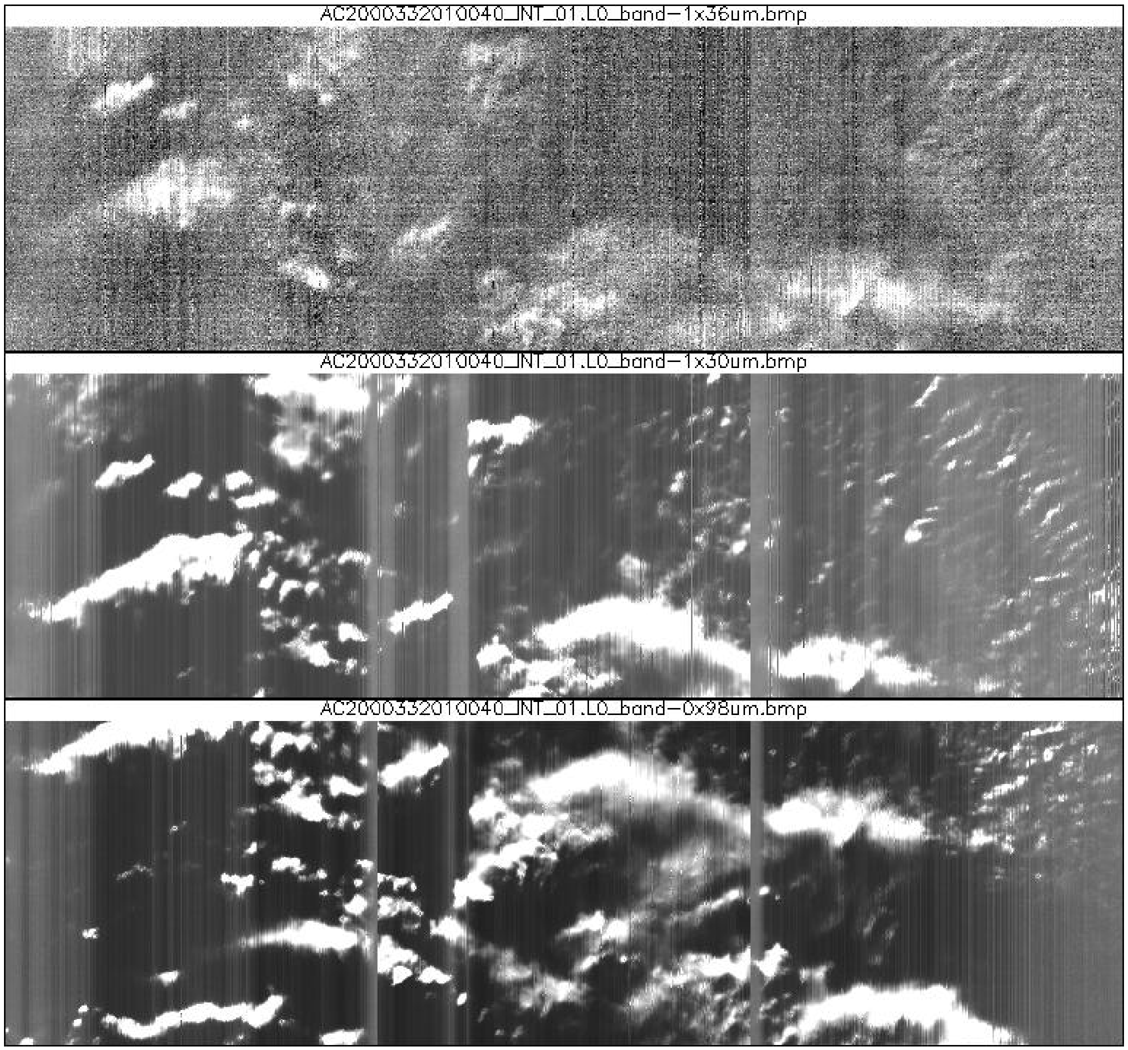


Image of Niger3 (1.383 mm Cirrus Channel)



First Hyperspectral Image from Space (Ocean Surface in Alaska). Water Vapor Attenuation Decreases Signal Near Band Center (1.385 micron)



1.36 micron

1.30 micron

0.98 micron

Surface Change Monitoring (e.g Shrinkage of Lakes)

TUMBARUMBA AUSTRALIA (LAKE HUME in CENTER)

1.26 micron

DECEMBER 25

Tumbarumba (Jupp/N) EO1091085200036111 1PP

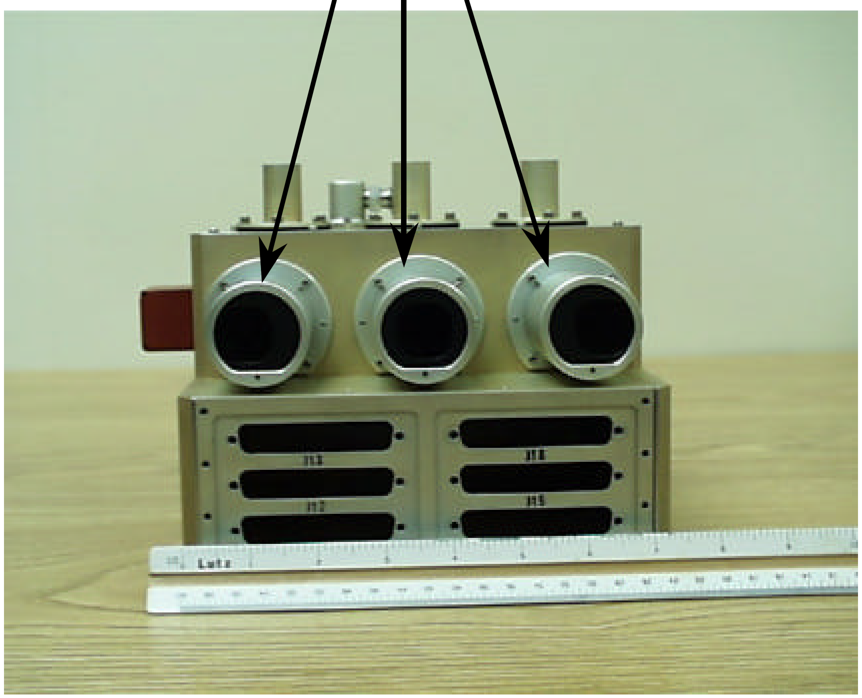
FEBRUARY 12

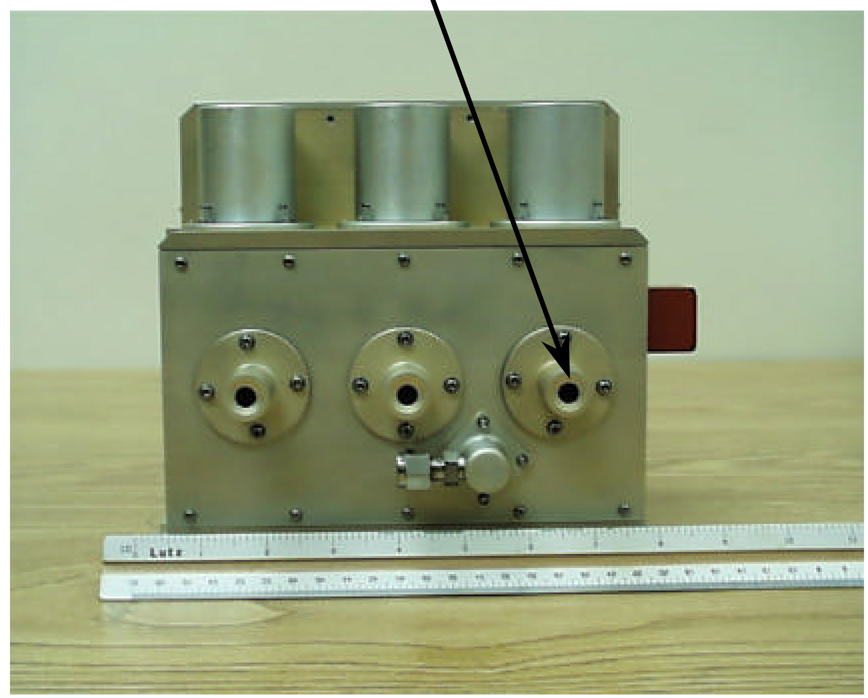
Tumbarumba [Jupp/N] EO1091085200104311 1PP

AC Triple Sensor System

Atmospheric Corrector has three independent sensors to cover 180km swath

Solar Illumination input provides calibration





Wideband Advanced Recorder Processor (WARP)

Description:

High Rate (up to 840Mbps capability), **high density** (48Gbit storage), **low weight** (less than 25.0 Kg) **Solid State Recorder/Processor with X-band modulation capability**.

Utilizes advanced integrated circuit packaging (3D stacked memory devices) and “chip on board” bonding techniques **to obtain extremely high density memory storage per board** (24Gbits/memory card)

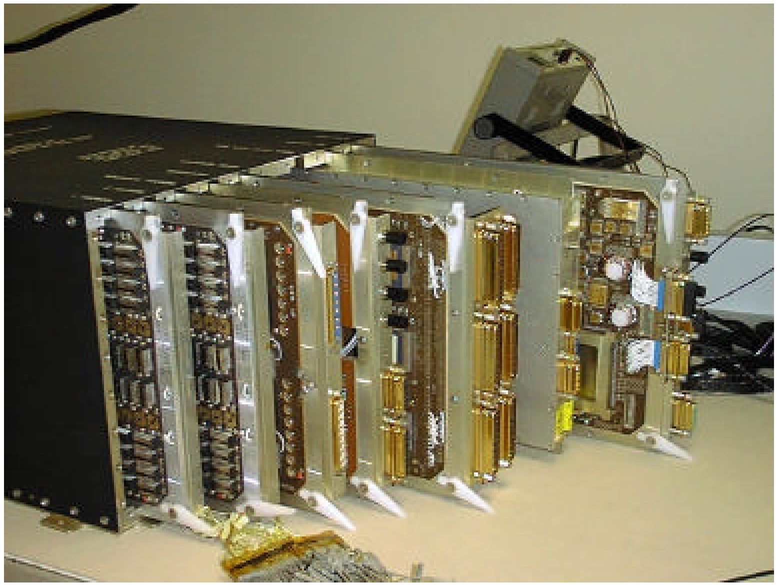
Includes high capacity Mongoose 5 **processor which can perform on-orbit data collection, compression and processing of land image scenes**.

Validation:

The WARP is required to store and transmit back science image files for the AC, ALI and Hyperion.

Partners:

GSFC and Litton Amecom



Benefits to Future Missions:

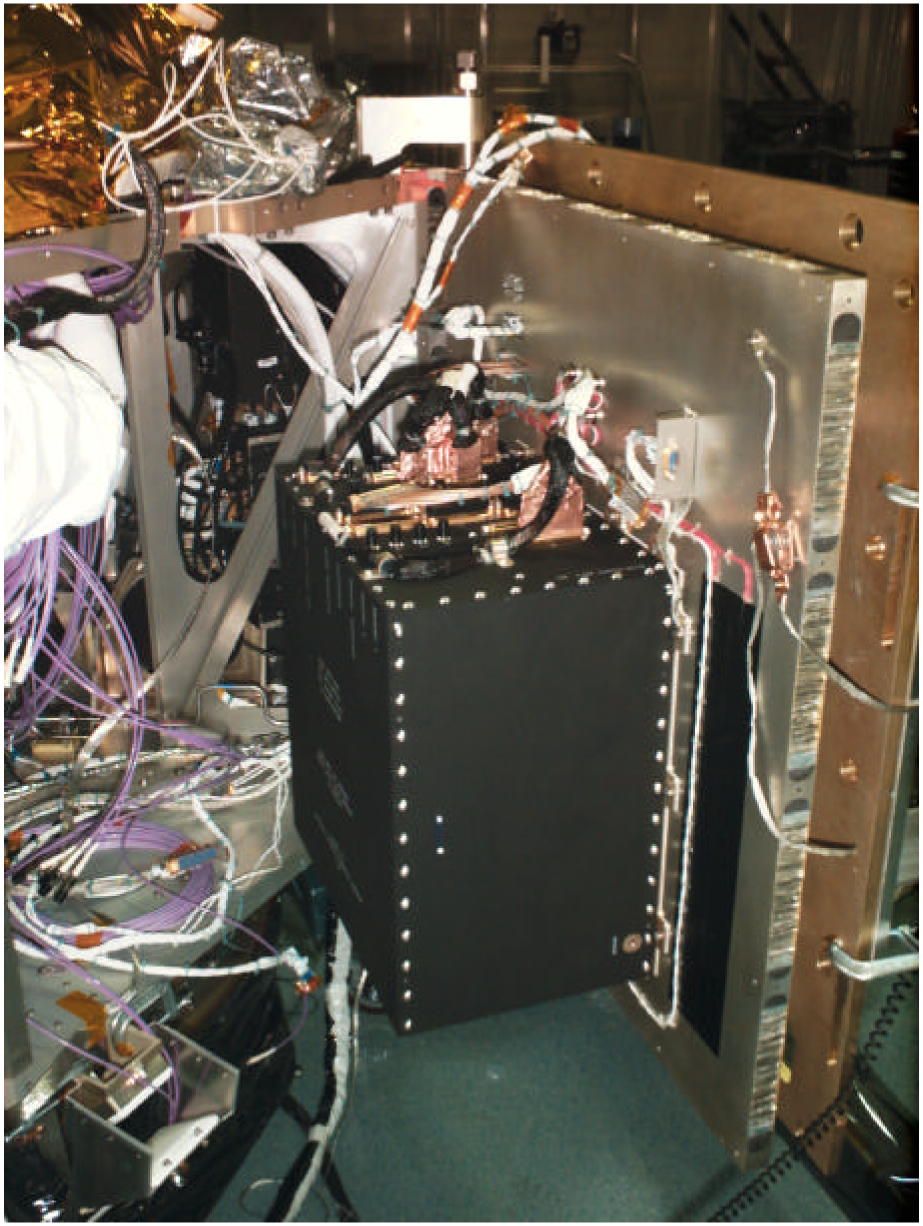
The WARP will validate a number of high density electronic board advanced packaging techniques and will provide the highest rate solid state recorder NASA has ever flown.

Its basic architecture and underlying technologies will be required for future earth imaging missions which need to collect, store and process high rate land imaging data.

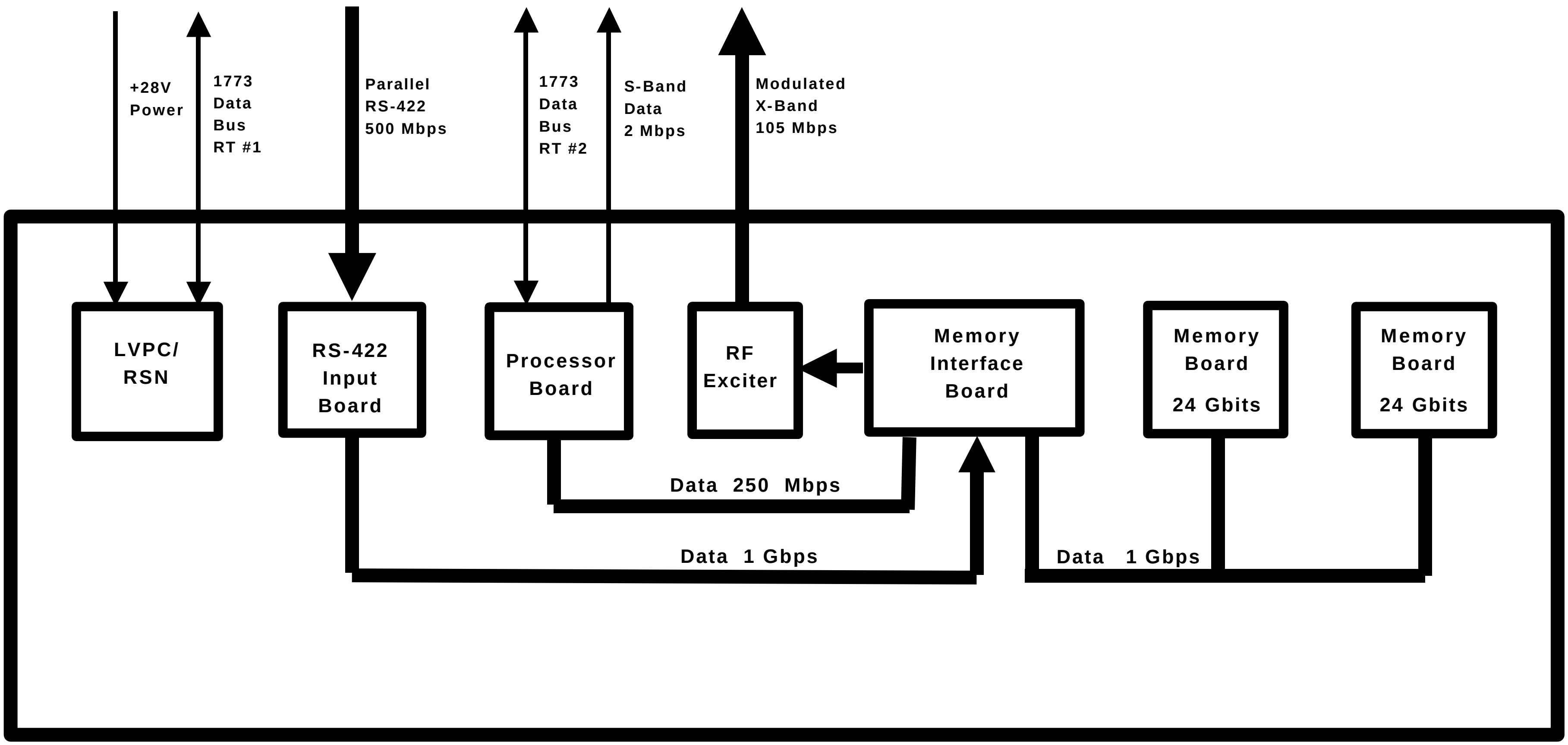
Top-Level Specifications

◆ *Data Storage:*	*48 Gbits*
◆ *Data Record Rate:*	*> 1 Gbps Burst*
	900 Mbps Continuous (6 times faster than L7 SSR)
◆ *Data Playback Rate:*	*105 Mbps X-Band (with built-in RF modulator)*
	2 Mbps S-Band
◆ *Data Processing:*	*Post-Record Data Processing Capability*
◆ *Size:*	*25 x 39 x 37 cm*
◆ *Mass:*	*22 kg*
◆ *Power:*	*38 W Orbital Average., 87 W Peak*
◆ *Thermal:*	*15 - 40 °C Minimum Operating Range*
◆ *Mission Life:*	*1 Year Minimum*
◆ *Radiation:*	*15 krad Minimum Total Dose, LET 35 MeV*

WARP on Spacecraft, Bay 1



WARP Flight Hardware Architecture



X-Band Phased Array Antenna (XPAA)

Technology Need:

High rate, reliable RF communication subsystems

Description:

The X-band phased array antenna is composed of a flat **grid of 64 radiating elements whose transmitted signals combine spatially to produce desired antenna directivity**

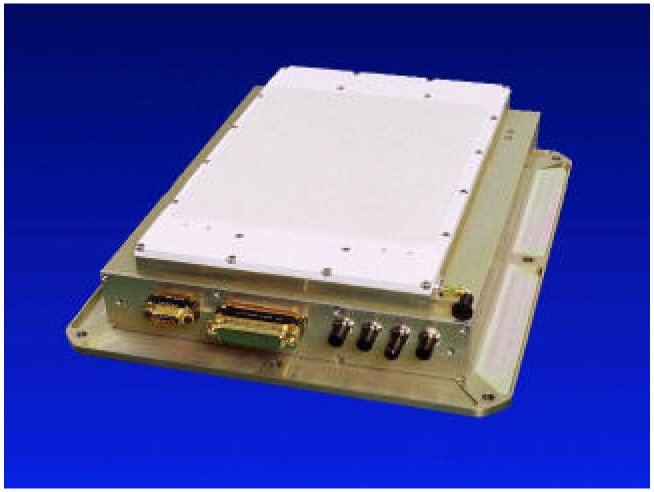
- *Avoids problems of deployable structures and moving parts*
- *Lightweight, compact, supports high downlink (100's Mbps) rates.*
- *Allows simultaneous instrument collection and data downlink.*

Validation:

The XPAA will be validated through measurement of bit error rate performance and effective ground station EIRP during science data downlinks over the lifetime of the mission.

Commercial Partners:

Boeing Phantom Works



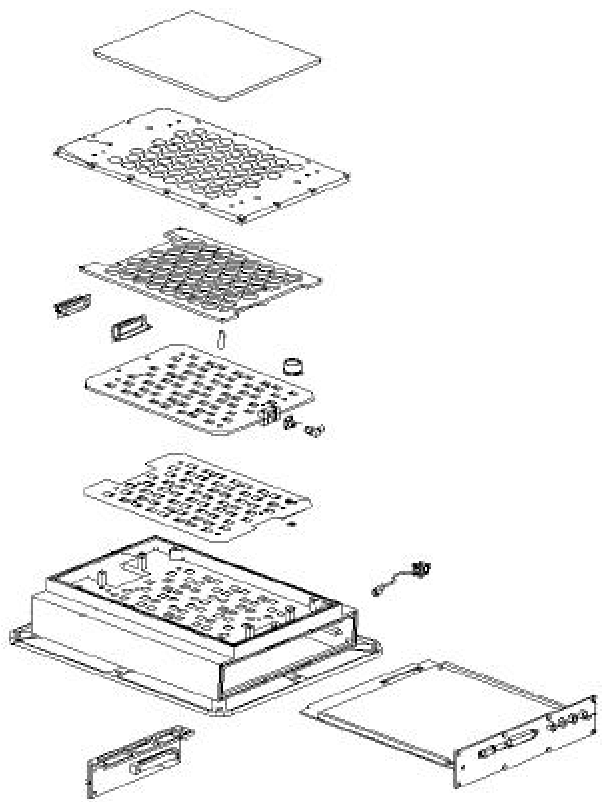
Benefits to Future Missions:

Future Earth Science missions will produce tera-bit daily data streams. The Phase Array antenna technology will enable:

- *Lower cost, weight and higher performance science downlinks*
- *Lower cost and size ground stations*
- *More flexible operations*

XPAA Performance Summary

- Frequency - 8225 MHz
- Bandwidth - 400 MHz
- Scan Coverage - 60 deg half-angle cone
- Radiating Elements - 64
- RF Input - 14 dBm
- EIRP - greater than 22 dBW at all commanded angles
- Polarization - LHCP
- Command Interface / Controller - 1773 / RSN
- Input DC Power - <58 watts over 0 to 40 C
- Mass - 5.5 kg



Enhanced Formation Flying (EFF)

Technology Need:

Constellation Flying

Description:

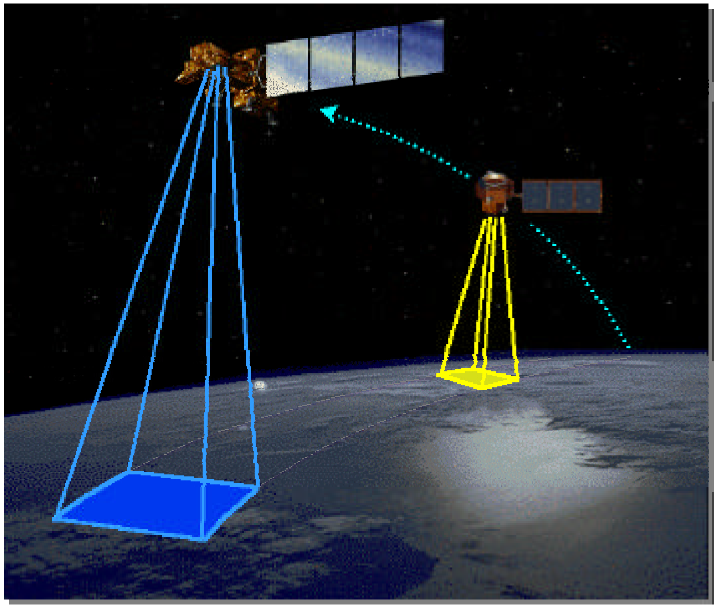
The enhanced formation flying (EFF) technology features **flight software that is capable of autonomously planning, executing**, and calibrating routine **spacecraft maneuvers to maintain satellites in their respective constellations** and formations.

Validation:

Validation of EFF will include demonstrating on-board autonomous capability to fly over Landsat 7 ground track within a +/- 3km while maintaining a one minute separation while an image is collected.

Partners:

JPL,GSFC, Hammers



Benefits to Future Missions:

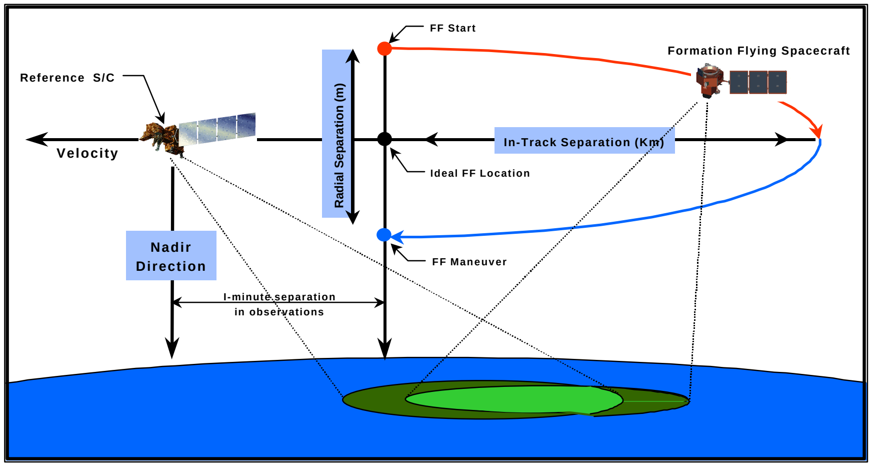
The EFF technology enables small, inexpensive spacecraft to fly in formation and gather concurrent science data in a “virtual platform.”

This “virtual platform” concept lowers total mission risk, increases science data collection and adds considerable flexibility to future Earth and space science missions.

Performance Required

- **Mission Orbit Requirements**
  - Paired scene comparison requires EO-1 to fly in formation with Landsat-7.
  - Maintain EO-1 orbit with tolerances of:
    - One minute separation between spacecraft
    - Maintain separation so that EO-1 follows current Landsat-7 ground track to +/- 3 km

- **Derived Orbit Requirements**
  - Approximately six seconds along-track separation tolerance (maps to +/- 3km with respect to earth rotation)
  - Plan maneuver in 12 hours
- **Derived Software Constraints**
  - Code Size approximately <655Kbytes
  - CPU Utilization approximately <50% Average over 10 Hours during maneuver planning
  - Less than 12 hours per maneuver plan



EO-1 Formation Maneuver Frequency Is Ballistic Dependent

Pulse Plasma Thruster (PPT)

Technology Need:

Increased payload mass fraction and precision attitude control

Description:

The Pulse Plasma Thruster is a small, self contained electromagnetic propulsion system which uses solid **Teflon propellant to deliver high specific impulses (900-1200sec), very low impulse bits (10-1000uN-s) at low power**.

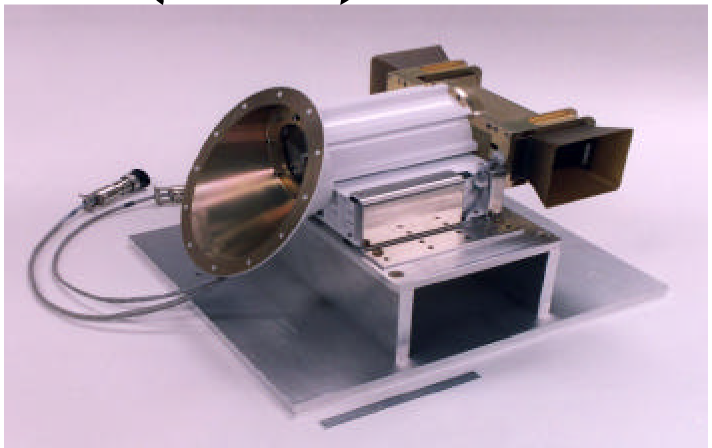
Advantages of this approach include:

- *Ideal candidate for a* ***low mass precision attitude control device****.*
- ***Replacement of reaction control wheels and other momentum unloading devices****. Increase in science payload mass fraction.*

Validation:

The PPT will be substituted (in place of a reaction wheel) during the later phase of the mission. Validation will include:

- *Demonstration of the PPT to provide precision pointing accuracy, response and stability.*
- *Confirmation of benign plume and EMI effects*



Benefits to Future Missions:

The PPT offers new lower mass and cost options for fine precision attitude control for new space or earth science missions

Partners

LeRC, Primex, GSFC

Carbon-Carbon Radiator

Technology Need:

Increase instrument payload mass fraction.

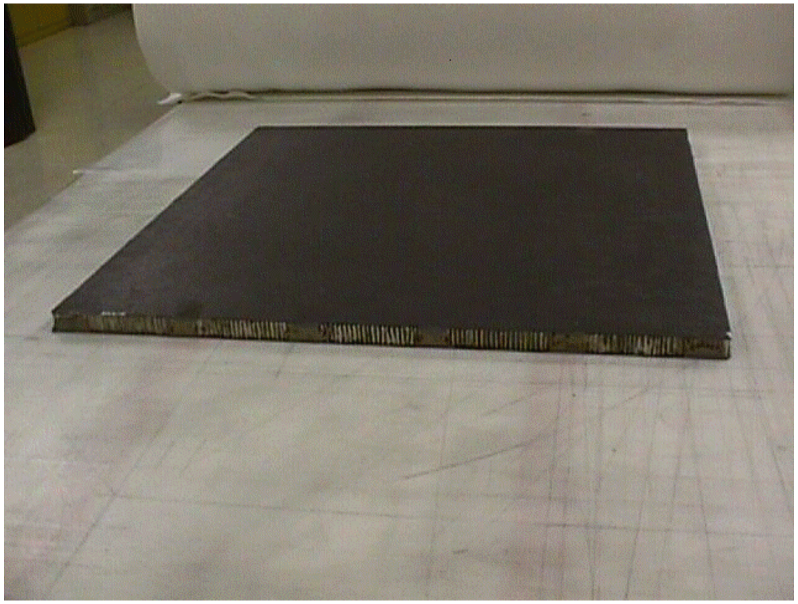
Description:

Carbon-Carbon is a special composite material that uses pure carbon for both the fiber and matrix. The NMP Earth Orbiter – 1 mission will be the first use of this material in a primary structure, serving as both an advanced thermal radiator and a load bearing structure Advantages of Carbon-Carbon include:

– ***High thermal conductivity*** *including through thickness*
– ***Good strength and weight characteristics***

Validation:

EO-1 will validate the Carbon-Carbon Radiator by replacing one of six aluminum 22” x 27” panels with one constructed using ***C-C face sheets and an aluminum honeycomb core***. Mechanical and thermal properties of the panels will be measured and trended during environmental testing and on-orbit.



Benefits to Future Missions:

This technology offers significant weight reductions over conventional aluminum structures allowing increased science payload mass fractions for Earth Science Missions. Higher thermal conductivity of C-C allows for more space efficient radiator designs.

Partners

CSRP (consortium of government and industry)

Lightweight Flexible Solar Array (LFSA)

Technology Need:

Increase payload mass fraction.

Description:

The LFSA is a lightweight photovoltaic(PV) solar array which uses thin film **Copper Indium Diselenide** solar cells and **shaped memory hinges** for deployment. Chief advantages of this technology are:

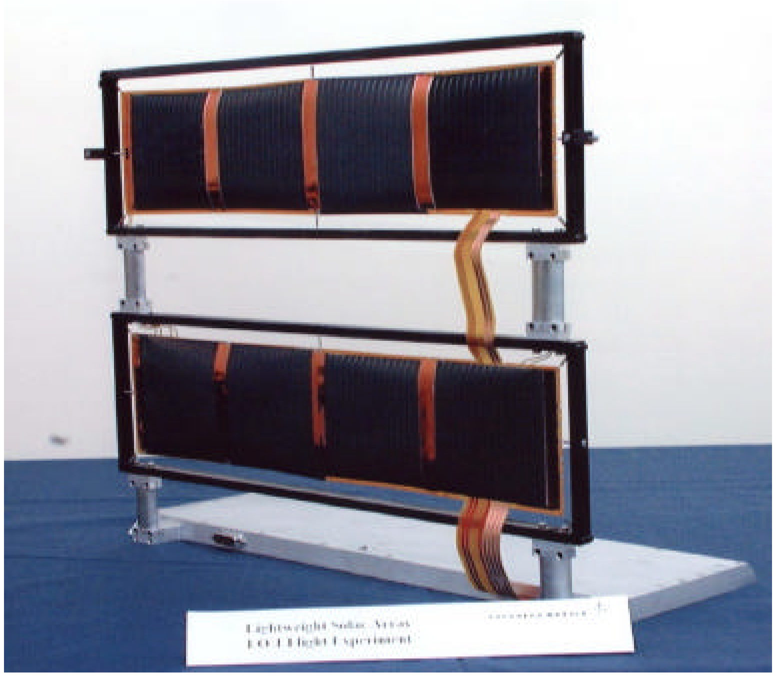
- *Greater than **100Watt/kg** specific energies **compared to** conventional Si/GaAs array which average **20-40 Watts/kg**.*
- ***Simple shockless deployment mechanism eliminates the need for more complex mechanical solar array deployment systems**. Avoids harsh shock to delicate instruments.*

Validation:

The LFSA deployment mechanism and power output will measured on-orbit to determine its ability to withstand long term exposure to radiation, thermal environment and degradation due to exposure to Atomic Oxygen.

Partners

Phillips Lab, Lockheed Martin Corp



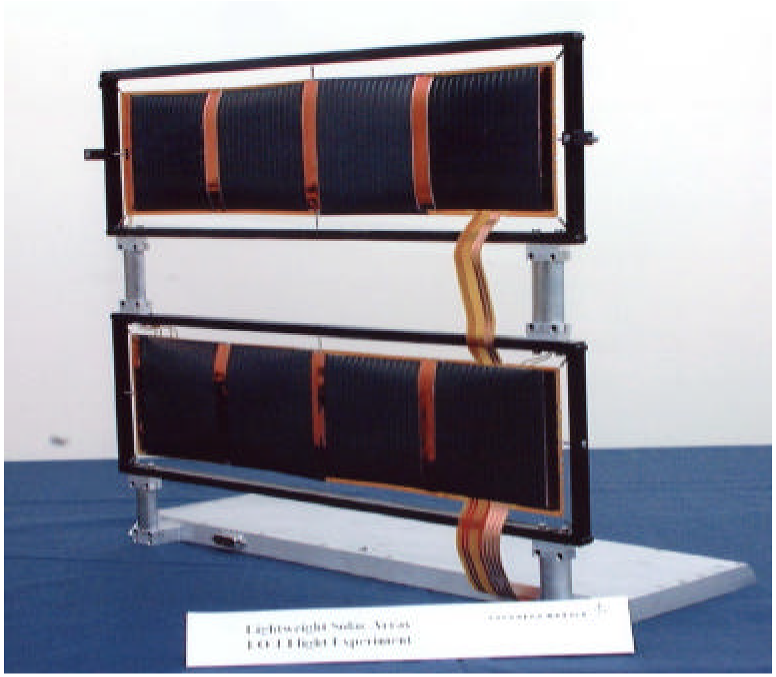
Benefits to Future Missions:

This technology provides much higher power to weight ratios (specific energy) which will enable future missions to increase science payload mass fraction.

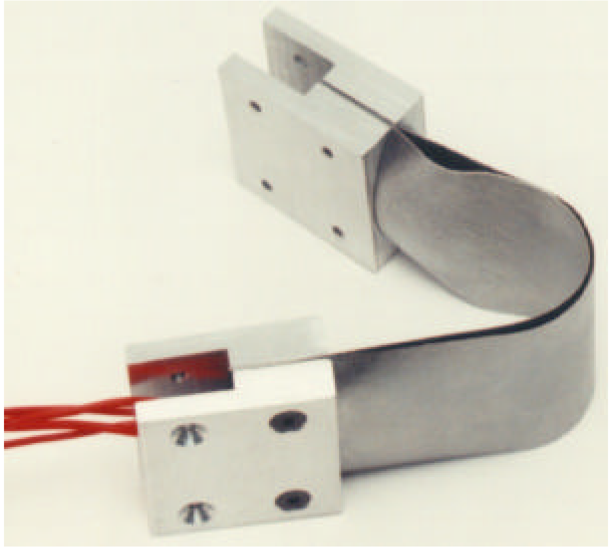
Description

- *Copper Indium Diselenide (CuInSe2 or CIS) Thin-Film Solar Cells*
- *Deposited on a Flexible Kapton Blanket suspended in a Composite Frame*
- *Frame Deployed Using Shape Memory NiTi Alloys and a Launch Restraint Device*
- *Advantage: Increase solar array w/kg (from typical 40 w/kg to >100 w/kg), increase science payload mass fraction*
- *Partners: AFRL (Kirtland AFB, NM), NASA/LaRC, Lockheed Martin (Denver, CO)*

Description (continued)



LFSA FLIGHT UNIT



Shaped Memory Alloy - STOWED

SMA - DEPLOYED

Summary

- *EO-1 was both a technical and a management challenge*
- *It was also very successful*
  - *Well on the way to validating a new technology instrument for the Landsat Continuity Mission*
  - *Validating technology for future exciting land use missions*
  - *Has taken over 500 images*
- *Learned how to do technology missions*
  - *Mission Technologist*
  - *Validation Plans*
  - *Infusion Plans*